

A STUDY OF FACTORS AFFECTING  
THRUST AUGMENTATION

Robert Gibson

Thesis  
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A STUDY OF FACTORS  
AFFECTING  
THRUST AUGMENTATION

A THESIS

by

Robert Gibson

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DAFO

CCRYA

FOOT

USA

1937

117



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1. The first part is devoted to the study of the properties of the function  $f(x)$ .
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4. The fourth part is devoted to the study of the properties of the function  $k(x)$ .
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6. The sixth part is devoted to the study of the properties of the function  $m(x)$ .
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LIST OF SYMBOLS

- A - Flow area sq. ft. ( on thermodynamic equations)  
mixing section.
- A - Flow area mixing section sq. in. (air ejector dimensions).
- a - Flow area sq. in. primary jet.
- F - Thrust Augmentation, lbs.
- g - Acceleration of gravity, 32.2 ft. per sec.<sup>2</sup>
- M - Mach number
- P<sub>0</sub> - Total pressure, lbs per sq. ft. abs.
- P - Static pressure lbs. per sq. ft. abs.
- R - Gas constant, 53.3 for air.
- T<sub>0</sub> - Total temperature, degrees Rankine.
- T - Static temperature, degrees Rankine.
- V - Velocity ft. per sec.
- W - Flow, lbs. per sec.
- C<sub>p</sub> - Specific heat at constant pressure, BTU per lb. per  
deg. R.
- ρ - Mass density, slugs per cu. ft.
- γ - (Constant) ratio of specific heats, 1.395 for air.

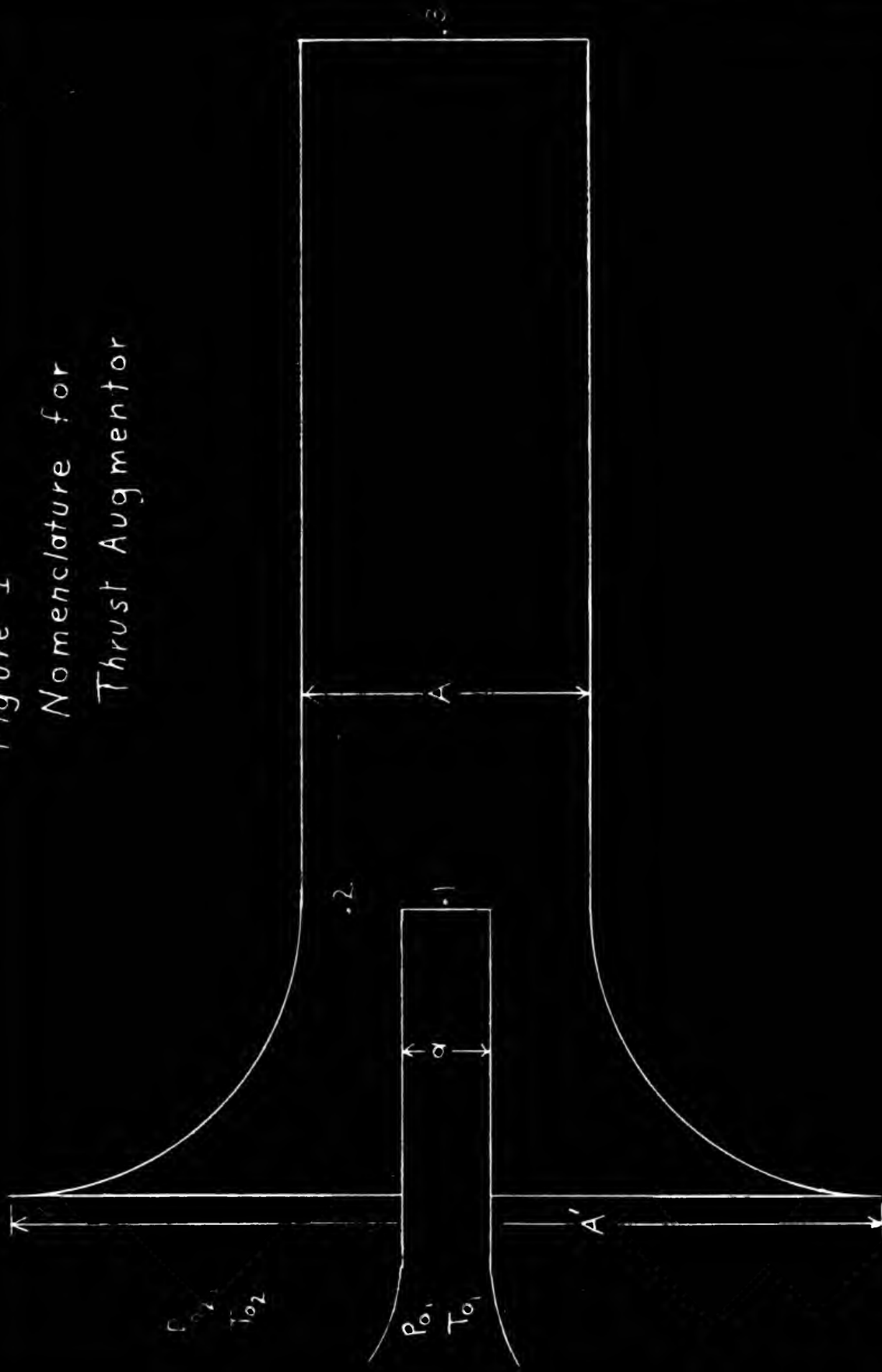
Subscripts and superscripts used will have the following meanings:

- ( )<sub>1</sub> - Primary air.
- ( )<sub>2</sub> - Secondary air at mixing section.
- ( )<sub>3</sub> - Mixed stream at augmentor exit.
- ( )<sub>2</sub><sup>1</sup> - Secondary air at augmentor entrance.
- ( )<sub>\*</sub> - Bibliography reference.





Figure I  
Nomenclature for  
Thrust Augmentor





## INTRODUCTION

The purpose of thrust augmentation is to transfer the kinetic energy leaving a jet to a larger mass of air by providing some material boundary upon which this larger mass can react. The additional thrust force is derived by the differences in fluid pressures on the surfaces of the augmentor. If a negative static pressure exists on the inner surface of a convergent shape by virtue of an increase in velocity from a total pressure common to both surfaces, the thrust comes from the difference between the internal and external integrated pressures.

In general, a jet directed into an augmentor mixes with and accelerates a larger quantity of low velocity secondary air. The discharge from the ejector will be a large mass of air with a lower velocity than that of the primary jet, and at some static pressure higher than that at the throat of the augmentor.

The purpose of these experiments is to show  
that the kinetic energy flowing in is a factor of the  
of particles and material density also which is largely  
due to mass. The additional energy flows is caused by  
the difference in field pressure on the surface of the  
material. It is assumed that pressure exists in the  
surface of a continuous field of lines of force. In  
velocity from a total pressure density is both constant, the  
change occurs that the difference between the internal and  
external pressures produces.

In general, a jet directed into an opening  
right into the material of a larger density of the velocity  
is reduced. The difference from the exterior will be a  
large mass of air with a lower velocity than that of the  
velocity jet, and at some static pressure higher than that  
at the throat of the opening.

PURPOSE

To determine the effect of various temperature ratios, pressure ratios, and area ratios upon the amount of static augmentation obtained with the view of finding the point of optimum design consistent with physical limitations.

2. The purpose of this study is to determine the effect of various factors on the rate of reaction between hydrogen peroxide and potassium iodide. The reaction is as follows:

$$2H_2O_2 + 2KI \rightarrow 2H_2O + 2KOH + I_2$$

The rate of reaction is measured by the time taken for a certain amount of iodine to be produced. The factors studied are the concentration of hydrogen peroxide, the concentration of potassium iodide, and the temperature of the reaction mixture.

The results of the experiment are shown in the following tables. Table 1 shows the effect of the concentration of hydrogen peroxide on the rate of reaction. Table 2 shows the effect of the concentration of potassium iodide on the rate of reaction. Table 3 shows the effect of temperature on the rate of reaction.

Table 1: Effect of the concentration of hydrogen peroxide on the rate of reaction.

Concentration of $H_2O_2$ (M)	Time taken for iodine to appear (s)
0.1	120
0.2	60
0.3	40
0.4	30
0.5	24

Table 2: Effect of the concentration of potassium iodide on the rate of reaction.

Concentration of $KI$ (M)	Time taken for iodine to appear (s)
0.1	120
0.2	60
0.3	40
0.4	30
0.5	24

Table 3: Effect of temperature on the rate of reaction.

Temperature ( $^{\circ}C$ )	Time taken for iodine to appear (s)
20	120
30	60
40	30
50	15

## HISTORY

The published material on air ejectors is voluminous but the application of air ejector theory to thrust augmentation has had very little coverage. At the present time, a large part of the thrust augmentation work that is being done is in a restricted category and the author was unsuccessful in obtaining any of the late reports.

The first tests of a thrust augmentor were made by Jacobs and Shoemaker in 1927.(1)\* They found that a maximum thrust of 1.4 times the theoretical free jet reaction. Mr. Donald C. Berkey of the General Electric Company also found experimentally that thrust was increased between 40 and 50 per cent by the addition of a thrust augmentor. (2)\*

In general, as stated above, the test results and theory of thrust augmentation have not been very thoroughly covered to date.

• List all employees in the following categories:

and the subject was undoubtedly an extremely rare case of the  
kind which is being done in a scientific manner  
and present time, a large part of the present population  
is being investigated and very little is known. It  
is known that the condition of air is not known to be

The first tests of a series suggested very much  
by Lewis and Zimmerman in 1927. The first test was  
conducted at 1.4 times the standard rate for  
velocity. Dr. Donald C. Lewis of the General Electric  
Company also found experimentally that current was  
increased between 40 and 60 per cent by the addition of  
a small amount of air.

in general, as stated above, the best possible  
and lowest of almost any material have not been  
theoretically covered to date.



## PART I

### THEORY

#### Fundamental principles.

The action of a jet is to accelerate a mass of air rearward producing a thrust which is equal to the mass times the acceleration. The greater the velocity in the wake the greater are the losses.

If this high velocity wake can be used to transfer energy to a larger mass of air, the momentum will be increased and the thrust of a unit would be increased, provided the losses would not be excessive. In effect, then, the exhaust would be a large mass of air at a moderate velocity rather than a small mass at a high velocity.

#### Design Parameters.

(a) Mixing tube length--Mixing tube length is defined as the distance from the exit of the primary nozzle to the end of the straight mixing duct. In the following work it is assumed that the mixing is complete and the pressure across the entrance to the mixing tube is constant. However, some length is needed to smooth the flow. If the mixing length is increased the friction effects become predominant and performance will be decreased. In this thesis, it was assumed that the mixing tube length would be found experimentally to

## Introduction

The object of this paper is to discuss the various methods of determining the relative values of the different types of goods and services which are produced in a community. It is assumed that the community is a closed one, and that the total amount of resources is fixed. The problem is to determine the relative values of the different types of goods and services which are produced in a community, given the total amount of resources and the technology of production. It is assumed that the community is a closed one, and that the total amount of resources is fixed. The problem is to determine the relative values of the different types of goods and services which are produced in a community, given the total amount of resources and the technology of production.

## Basic Definitions

(1) Relative Value—The relative value of a good or service is the ratio of its value to the value of a standard good or service. It is assumed that the standard good or service is a good or service which is produced in the community, and that its value is fixed. The relative value of a good or service is determined by the ratio of its value to the value of the standard good or service. It is assumed that the standard good or service is a good or service which is produced in the community, and that its value is fixed. The relative value of a good or service is determined by the ratio of its value to the value of the standard good or service.

bring the Mach number to such a value that the static pressure of the discharge would be equal to atmospheric pressure. Other investigators have found that an L/D of from 4 to 8 is the optimum. One investigator found that an L/D of about 7 was the best. (2)\*

(b) Mixing section area ratio. This ratio is the ratio of mixing tube area to the area of the primary jet. This is one of the variables in the following analysis and will be discussed further.

(c) Ratio of mixing tube area to thrust augmentor entrance area. Since the difference between these two areas is the projected area upon which the external pressure acts, it is to be expected that augmentation will increase as the area difference increases.

(d) Temperature ratio. This is the ratio of the temperature of the primary jet to that of the secondary air. This will be covered by later analysis.

(e) Pressure ratio. The total pressure ratio of the primary stream to that of the secondary stream. This will also be covered by a later analysis.

### Theoretical Analysis.

(1) Equations for calculation of constant area mixing air ejector.

Since a thrust augmentor is basically an air

1. The purpose of this report is to provide a summary of the results of the investigation.

2. The investigation was conducted in accordance with the following objectives:

3. The results of the investigation are as follows:

4. The following conclusions were drawn from the investigation:

5. The following recommendations are made for future work:

6. The following conclusions were drawn from the investigation:

7. The following recommendations are made for future work:

8. The following conclusions were drawn from the investigation:

9. The following recommendations are made for future work:

10. The following conclusions were drawn from the investigation:

11. The following recommendations are made for future work:

12. The following conclusions were drawn from the investigation:

13. The following recommendations are made for future work:

14. The following conclusions were drawn from the investigation:

15. The following recommendations are made for future work:

16. The following conclusions were drawn from the investigation:

17. The following recommendations are made for future work:

18. The following conclusions were drawn from the investigation:

19. The following recommendations are made for future work:

20. The following conclusions were drawn from the investigation:

21. The following recommendations are made for future work:

22. The following conclusions were drawn from the investigation:

23. The following recommendations are made for future work:

24. The following conclusions were drawn from the investigation:

25. The following recommendations are made for future work:

26. The following conclusions were drawn from the investigation:

ejector, the air ejector equations are applicable. It has been shown by several investigators (2)\* (3)\* that maximum augmentation will be obtained from a constant area mixing ejector. This is fairly obvious since for a constant pressure mixing, a diverging section would be required and the integrated forces would be decreased by the forces acting on the diverging section.

The following assumptions were made.

- (1) The gases are air with constant specific heats.
- (2) The ratio of specific heats is 1.395.
- (3) Total momentum per second is constant.
- (4) The expansion of secondary air into the mixing section is reversible.
- (5) The weight of fuel added in the primary jet is negligible compared to that of the air.

The theoretical analysis of air ejectors was taken from the analysis presented by Prof. Neil P. Bailey in his Thermodynamics of High Velocity Flow. (4)\*

In the constant area section of an air ejector, if wall friction is ignored, the total momentum per second at 1-2 is the same as that at 3, or

$$P_1 A + \rho_1 v_1 A v_1 + P_2 (A-a) + \rho_2 v_2 (A-a) v_2 = P_3 A + \rho_3 v_3 A v_3 \dots (1)$$



but

$$P = \frac{P}{gRT} \dots\dots\dots(2)$$

$$P_1 a + \frac{P_1}{gRT_1} v_1^2 a + P_2 (A-a) + \frac{P_2}{gRT_2} v_2^2 (A-a) = P_3 A + \frac{P_3}{gRT_3} v_3^2 A$$

$$M = \frac{v}{\sqrt{\gamma g R T}} \dots\dots\dots(3)$$

$$P_1 a + P_1 a \gamma M_1^2 + P_2 (A-a) + P_2 (A-a) \gamma M_2^2 = P_3 A + P_3 A \gamma M_3^2$$

$$P_1 a (1 + \gamma M_1^2) + P_2 (A-a) (1 + \gamma M_2^2) = P_3 A (1 + \gamma M_3^2) \dots\dots\dots(4)$$

but from (4)\*

$$\frac{W \sqrt{T_0}}{PA} = M \sqrt{\frac{\gamma g}{R} \left[ 1 + \frac{\gamma-1}{2} M^2 \right]} \dots\dots\dots(5)$$

$$PA = \frac{W \sqrt{T_0}}{M \sqrt{\frac{\gamma g}{R} \left[ 1 + \frac{\gamma-1}{2} M^2 \right]}} \dots\dots\dots(6)$$

$$W_1 + W_2 = W_3 \dots\dots\dots(7)$$

(4), (6) and (7) gives

$$\frac{W_1 \sqrt{T_{01}} (1 + \gamma M_1^2)}{M_1 \sqrt{\frac{\gamma g}{R} \left[ 1 + \frac{\gamma-1}{2} M_1^2 \right]}} + \frac{W_2 \sqrt{T_{02}} (1 + \gamma M_2^2)}{M_2 \sqrt{\frac{\gamma g}{R} \left[ 1 + \frac{\gamma-1}{2} M_2^2 \right]}} = \frac{(W_1 + W_2) \sqrt{T_{03}} (1 + \gamma M_3^2)}{M_3 \sqrt{\frac{\gamma g}{R} \left[ 1 + \frac{\gamma-1}{2} M_3^2 \right]}} \dots\dots\dots(8)$$

A heat balance gives,

$$W_1 C_p T_{01} + W_2 C_p T_{02} = (W_1 + W_2) C_p T_{03} \dots\dots\dots(9)$$

$$(2) \dots\dots\dots = 7$$

$$1 + \frac{1}{x^2} + \frac{1}{x^4} = (1 + \frac{1}{x^2})^2 = 1 + \frac{2}{x^2} + \frac{1}{x^4}$$

$$(3) \dots\dots\dots = 8$$

$$\frac{1}{x^2} + \frac{1}{x^4} + \frac{1}{x^6} = \frac{1}{x^2} (1 + \frac{1}{x^2} + \frac{1}{x^4}) = \frac{1}{x^2} (1 + \frac{1}{x^2})^2 = \frac{1}{x^2} (1 + \frac{2}{x^2} + \frac{1}{x^4}) = \frac{1}{x^2} + \frac{2}{x^4} + \frac{1}{x^6}$$

$$(4) \dots\dots\dots = 9$$

$$(5) \dots\dots\dots = 10$$

$$(6) \dots\dots\dots = 11$$

$$(7) \dots\dots\dots = 12$$

$$\frac{1}{x^2} + \frac{1}{x^4} + \frac{1}{x^6} + \frac{1}{x^8} = \frac{1}{x^2} (1 + \frac{1}{x^2} + \frac{1}{x^4} + \frac{1}{x^6}) = \frac{1}{x^2} (1 + \frac{1}{x^2})^3 = \frac{1}{x^2} (1 + \frac{3}{x^2} + \frac{3}{x^4} + \frac{1}{x^6}) = \frac{1}{x^2} + \frac{3}{x^4} + \frac{3}{x^6} + \frac{1}{x^8}$$

$$(8) \dots\dots\dots = 13$$

$$(9) \dots\dots\dots = 14$$

$$\frac{1}{x^2} + \frac{1}{x^4} + \frac{1}{x^6} + \frac{1}{x^8} + \frac{1}{x^{10}} = \frac{1}{x^2} (1 + \frac{1}{x^2} + \frac{1}{x^4} + \frac{1}{x^6} + \frac{1}{x^8}) = \frac{1}{x^2} (1 + \frac{1}{x^2})^4 = \frac{1}{x^2} (1 + \frac{4}{x^2} + \frac{6}{x^4} + \frac{4}{x^6} + \frac{1}{x^8}) = \frac{1}{x^2} + \frac{4}{x^4} + \frac{6}{x^6} + \frac{4}{x^8} + \frac{1}{x^{10}}$$

$$(10) \dots\dots\dots = 15$$

$$(11) \dots\dots\dots = 16$$

$$(12) \dots\dots\dots = 17$$



Assuming Cp constant,

$$T_{o3} = T_{o1} + \frac{W_2}{W_1} T_{o2} \dots\dots\dots(10)$$

$$\frac{1 + \frac{W_2}{W_1}}{W_1}$$

Combining (8) & (10)

$$\frac{W_1 \sqrt{T_{o1}} (1 + \gamma M_1^2)}{M_1 \sqrt{\frac{\gamma g}{R} \left[ 1 + \frac{\gamma-1}{2} M_1^2 \right]}} + \frac{W_2 \sqrt{T_{o2}} (1 + \gamma M_2^2)}{M_2 \sqrt{\frac{\gamma g}{R} \left[ 1 + \frac{\gamma-1}{2} M_2^2 \right]}} =$$

$$\frac{(W_1 + W_2) \left[ \frac{T_{o1} + \frac{W_2}{W_1} T_{o2}}{1 + \frac{W_2}{W_1}} \right]^{\frac{1}{\gamma}} (1 + \gamma M_3^2)}{M_3 \sqrt{\frac{\gamma g}{R} \left[ 1 + \frac{\gamma-1}{2} M_3^2 \right]}} \dots\dots\dots(11)$$

or

$$\frac{1 + \gamma M_1^2}{M_1 \sqrt{\frac{\gamma g}{R} \left[ 1 + \frac{\gamma-1}{2} M_1^2 \right]}} + \frac{W_2}{W_1} \sqrt{\frac{T_{o2}}{T_{o1}}} \frac{(1 + \gamma M_2^2)}{M_2 \sqrt{\frac{\gamma g}{R} \left[ 1 + \frac{\gamma-1}{2} M_2^2 \right]}} =$$

$$\sqrt{\frac{(1 + \frac{W_2}{W_1}) \left[ 1 + \frac{W_2}{W_1} \frac{T_{o2}}{T_{o1}} \right]}{1 + \gamma M_3^2}} \frac{1 + \gamma M_3^2}{M_3 \sqrt{\frac{\gamma g}{R} \left[ 1 + \frac{\gamma-1}{2} M_3^2 \right]}} \dots\dots\dots(12)$$

(10).....

$$\frac{1}{x^2 + 1}$$

(11).....

$$= \frac{\pi^2 \sqrt{\frac{x}{2}} \left[ 1 + \frac{x-1}{2} \right]}{\pi^2 \sqrt{\frac{x}{2}} \left[ 1 + \frac{x-1}{2} \right]} + \frac{\pi^2 \sqrt{\frac{x}{2}} \left[ 1 + \frac{x-1}{2} \right]}{\pi^2 \sqrt{\frac{x}{2}} \left[ 1 + \frac{x-1}{2} \right]}$$

(12).....

$$\frac{\left[ \frac{1}{x^2} + \frac{1}{x^2} + \frac{1}{x^2} \right]}{\pi^2 \sqrt{\frac{x}{2}} \left[ 1 + \frac{x-1}{2} \right]}$$

or

$$= \frac{\pi^2 \sqrt{\frac{x}{2}} \left[ 1 + \frac{x-1}{2} \right]}{\pi^2 \sqrt{\frac{x}{2}} \left[ 1 + \frac{x-1}{2} \right]} + \frac{\pi^2 \sqrt{\frac{x}{2}} \left[ 1 + \frac{x-1}{2} \right]}{\pi^2 \sqrt{\frac{x}{2}} \left[ 1 + \frac{x-1}{2} \right]}$$

$$\sqrt{\frac{1}{x^2} + \frac{1}{x^2} + \frac{1}{x^2}} \left[ 1 + \frac{x-1}{2} \right] = \frac{\pi^2 \sqrt{\frac{x}{2}} \left[ 1 + \frac{x-1}{2} \right]}{\pi^2 \sqrt{\frac{x}{2}} \left[ 1 + \frac{x-1}{2} \right]}$$

Which gives,

$$\frac{(1 + \gamma M_3^2)}{M_3 \sqrt{\frac{\gamma g}{R} \left(1 + \frac{\gamma - 1}{2} M_3^2\right)}} = \frac{1}{\sqrt{\left(1 + \frac{W_2}{W_1}\right) \left(1 + \frac{W_2}{W_1} \frac{T_{02}}{T_{01}}\right)}} \times$$

$$\left[ \frac{1 + \gamma M_1^2}{M_1 \sqrt{\frac{\gamma g}{R} \left(1 + \frac{\gamma - 1}{2} M_1^2\right)}} + \frac{W_2}{W_1} \sqrt{\frac{T_{02}}{T_{01}}} \frac{1 + \gamma M_2^2}{M_2 \sqrt{\frac{\gamma g}{R} \left(1 + \frac{\gamma - 1}{2} M_2^2\right)}} \right] \dots\dots(13)$$

The above equation can be used for solution of:

$M_3$ ; provided that  $M_1$ ,  $M_2$ , and  $\frac{T_{02}}{T_{01}}$  are known. To facilitate

solution, plots of  $\frac{(1 + \gamma M^2)}{M \sqrt{\frac{\gamma g}{R} \left(1 + \frac{\gamma - 1}{2} M^2\right)}}$  vs  $M$  are included

in curve numbers 1-L to 1-P inclusive.

Values of the theoretical weight ratio may be found from the dimensions of the specific air ejector and a plot of the function  $M \sqrt{\frac{\gamma g}{R} \left(1 + \frac{\gamma - 1}{2} M^2\right)}$  vs  $M$  (curves 1-H to 1-K) from equation (5) as follows:

$$\frac{W_1 \sqrt{T_{01}}}{aP_1} = M_1 \sqrt{\frac{\gamma g}{R} \left(1 + \frac{\gamma - 1}{2} M_1^2\right)} \dots\dots\dots(14)$$

$$\frac{W_2 \sqrt{T_{02}}}{(A-a)P_2} = M_2 \sqrt{\frac{\gamma g}{R} \left(1 + \frac{\gamma - 1}{2} M_2^2\right)} \dots\dots\dots(15)$$

$$x = \frac{\sqrt{1 + \frac{1}{2} \left( \frac{1}{2} + \frac{1}{2} \right)}}{\sqrt{1 + \frac{1}{2} \left( \frac{1}{2} + \frac{1}{2} \right)}}$$

$$x = \frac{\sqrt{1 + \frac{1}{2} \left( \frac{1}{2} + \frac{1}{2} \right)}}{\sqrt{1 + \frac{1}{2} \left( \frac{1}{2} + \frac{1}{2} \right)}}$$

The above equation can be used for solving the

equation of the form  $x^2 + \frac{1}{2}x + \frac{1}{2} = 0$  by putting  $x = \frac{1}{2}y$

$$y^2 + y + 1 = 0 \quad \text{or } y = \frac{-1 \pm \sqrt{1 - 4}}{2}$$

in which  $y = 1$  or  $y = -1$  is the solution.

Values of the function  $f(x)$  which satisfy the

equation  $f(x) = 0$  are the solutions of the equation  $f(x) = 0$

and of the form  $f(x) = \frac{1}{2} \left( 1 + \frac{1}{2} \right)$  or  $f(x) = \frac{1}{2} \left( 1 - \frac{1}{2} \right)$

$$f(x) = \frac{1}{2} \left( 1 + \frac{1}{2} \right) \quad \text{or} \quad f(x) = \frac{1}{2} \left( 1 - \frac{1}{2} \right)$$

$$f(x) = \frac{1}{2} \left( 1 + \frac{1}{2} \right) \quad \text{or} \quad f(x) = \frac{1}{2} \left( 1 - \frac{1}{2} \right)$$

For  $P_1 = P_2$ ,

$$\frac{W_2}{W_1} = \frac{(A-a) \sqrt{\frac{T_{o1}}{T_{o2}}}}{M_1 \sqrt{\frac{\gamma g}{R} \left(1 + \frac{\gamma-1}{2} M_1^2\right)}} \cdot \frac{M_2 \sqrt{\frac{\gamma g}{R} \left(1 + \frac{\gamma-1}{2} M_2^2\right)}}{\dots\dots\dots(16)}$$

With  $M_1$  and  $M_2$  known, then  $W_2$  can be calculated from

$\frac{W_1}{W_1}$   
(16) and  $M_3$  calculated from equation (13).  $\frac{W_3 \sqrt{T_{o3}}}{AP_3}$  then  
can be found from curves 1-H to 1-K.

Calculation of  $P_3/P_1$ .

$$aP_1 = \frac{W_1 \sqrt{T_{o1}}}{\left(\frac{W_1 \sqrt{T_{o1}}}{aP_1}\right)} \dots\dots\dots(17)$$

and,

$$(A-a)P_1 = \frac{W_2 \sqrt{T_{o2}}}{\left(\frac{W_2 \sqrt{T_{o2}}}{(A-a)P_1}\right)} = AP_1 - aP_1 \dots\dots\dots(18)$$

therefore,

$$AP_1 = \frac{W_2 \sqrt{T_{o2}}}{\left(\frac{W_2 \sqrt{T_{o2}}}{(A-a)P_1}\right)} + \frac{W_1 \sqrt{T_{o1}}}{\left(\frac{W_1 \sqrt{T_{o1}}}{aP_1}\right)} \dots\dots\dots(19)$$

From equation (10),

$$T_{o3} = \frac{W_1 T_{o1} + W_2 T_{o2}}{W_1 + W_2} \dots\dots\dots(20)$$

$$(11) \dots \dots \dots \frac{\frac{1}{\sqrt{1-\beta^2}} \left( \frac{1}{\sqrt{1-\beta^2}} \frac{1}{\sqrt{1-\beta^2}} \right)}{\frac{1}{\sqrt{1-\beta^2}} \left( \frac{1}{\sqrt{1-\beta^2}} \frac{1}{\sqrt{1-\beta^2}} \right)} = \frac{1}{\sqrt{1-\beta^2}}$$

With  $\beta_1$  and  $\beta_2$  known, then  $\beta$  can be calculated from

$$\frac{\beta}{1-\beta^2}$$

(10) and  $\beta$  calculated from equation (10) can be found from curve 1-4 to 1-5.

Calculation of  $\beta$  is

$$(12) \dots \dots \dots \frac{\frac{1}{\sqrt{1-\beta^2}} \left( \frac{1}{\sqrt{1-\beta^2}} \frac{1}{\sqrt{1-\beta^2}} \right)}{\left( \frac{1}{\sqrt{1-\beta^2}} \right)} = \frac{1}{\sqrt{1-\beta^2}}$$

and

$$(13) \dots \dots \dots \frac{1}{\sqrt{1-\beta^2}} = \frac{1}{\sqrt{1-\beta^2}} \left( \frac{1}{\sqrt{1-\beta^2}} \right)$$

Therefore

$$(14) \dots \dots \dots \frac{1}{\sqrt{1-\beta^2}} + \frac{1}{\sqrt{1-\beta^2}} = \frac{1}{\sqrt{1-\beta^2}}$$

From equation (14)

$$(15) \dots \dots \dots \frac{2\sqrt{1-\beta^2}}{1-\beta^2} = \frac{1}{\sqrt{1-\beta^2}}$$

or,

$$\sqrt{T_{o3}} = \sqrt{\frac{W_1 T_{o1} + W_2 T_{o2}}{W_1 + W_2}} \dots\dots\dots(21)$$

then,

$$(W_1 + W_2) \sqrt{T_{o3}} = \sqrt{(W_1 + W_2)(W_1 T_{o1} + W_2 T_{o2})} \dots\dots\dots(22)$$

and

$$\frac{(W_1 + W_2) \sqrt{T_{o3}}}{AP_3} = \frac{\sqrt{(W_1 + W_2)(W_1 T_{o1} + W_2 T_{o2})}}{A_1 P_3} \dots\dots\dots(23)$$

$$AP_3 = AP_1 \frac{P_3}{P_1} \dots\dots\dots(24)$$

Combining equations (19), (23), and (24),

$$\frac{(W_1 + W_2) \sqrt{T_{o3}}}{AP_3} = \frac{\sqrt{(W_1 + W_2)(W_1 T_{o1} + W_2 T_{o2})}}{\frac{P_3}{P_1} \left[ \frac{\frac{W_2 \sqrt{T_{o2}}}{(A-a)P_2} + \frac{W_1 \sqrt{T_{o1}}}{W_1 \sqrt{T_{o1}}}}{\frac{W_2 \sqrt{T_{o2}}}{(A-a)P_2} + \frac{W_1 \sqrt{T_{o1}}}{dP_1}} \right]} \dots\dots\dots(25)$$

Dividing numerator and denominator by  $W_1 T_{o1}$

$$\frac{P_3}{P_1} = \frac{\sqrt{\left(1 + \frac{W_2}{W_1}\right) \left(1 + \frac{W_2 T_{o2}}{W_1 T_{o1}}\right)}}{\frac{(W_1 + W_2) \sqrt{T_{o3}}}{AP_3} \left[ \frac{\frac{W_2 \sqrt{T_{o2}}}{W_1 \sqrt{T_{o1}}} + \frac{1}{W_1 \sqrt{T_{o1}}}}{\frac{W_2 \sqrt{T_{o2}}}{(A-a)P_2} + \frac{1}{dP_1}} \right]} \dots\dots\dots(26)$$

(141).....

$$\frac{1}{x^2 + 1} = \frac{1}{x^2 + 1}$$

(142).....

$$\frac{1}{x^2 + 1} = \frac{1}{x^2 + 1}$$

(143).....

$$\frac{1}{x^2 + 1} = \frac{1}{x^2 + 1}$$

(144).....

$$\frac{1}{x^2 + 1} = \frac{1}{x^2 + 1}$$

(145).....

$$\frac{1}{x^2 + 1} = \frac{1}{x^2 + 1}$$

Divide numerator and denominator by  $x^2$

(146).....

$$\frac{1}{x^2 + 1} = \frac{1}{x^2 + 1}$$



From equation (26) the static pressure at the point of mixing can be calculated.

### Calculation of $M_2$ , and $P_0/P_{2'}$

For any value of  $M_2$  and with given physical dimensions for the augmentor,  $M_2$ , can be calculated.

From the relation (4)\*

$$\frac{A}{A_0} = \frac{M_0}{M} \left( \frac{1 + \frac{\gamma-1}{2} M^2}{1 + \frac{\gamma-1}{2} M_0^2} \right)^{\frac{\gamma+1}{2(\gamma-1)}} \dots\dots\dots(27)$$

Curve 1-F is a plot of the above relation vs  $M$  using  $A_0$  as unity where  $M_0 = 1.0$ . This curve gives the value  $A-a/A_0$  at  $M_2$ .

Then

$$\left( \frac{A-a}{A_0} \right) \times \left( \frac{A'-a}{A_0} \right) = \left( \frac{A'-a}{A_0} \right) \dots\dots\dots(28)$$

The value of  $M_2$ , can be found at the value of  $A'-a/A_0$  on curve 1-G.

To find  $P_0/P_{2'}$ , the following relation from (1) is used:

$$\frac{P_0}{P} = \left( 1 + \frac{\gamma-1}{2} M^2 \right)^{\frac{\gamma}{\gamma-1}} \dots\dots\dots(29)$$

Curve 1-A for low values of  $P_0/P$  vs  $M$  has been plotted and

$P_0/P_{2'}$ , can be obtained directly using the value of  $M_2$  obtained.

Calculation of  $\gamma$  and  $\gamma_{\infty}$

For any value of  $K_2$  and with given physical dimensions for the auger,  $K_2$  can be calculated.

From the relation (4) a

.....(5)

$$\frac{A}{A_0} = \frac{K_2}{K_2} \left( \frac{1 + \frac{1}{K_2}}{1 + \frac{1}{K_2}} \right)^{\frac{1}{2}} \left( \frac{1 + \frac{1}{K_2}}{1 + \frac{1}{K_2}} \right)^{\frac{1}{2}}$$

Curve 1-7 is a plot of the above relation vs  $K_2$

which is unity when  $K_2 = 1.0$ . This curve gives the

value  $K_2 = \sqrt{A/A_0}$  at  $K_2$ .

From

$$\frac{(A/A_0)}{K_2} = \frac{(A/A_0)}{K_2} \times \frac{(A/A_0)}{K_2} = \frac{(A/A_0)}{K_2}$$

The value of  $K_2$  can be found at the value of  $A/A_0$  on

curve 1-6.

To find  $\gamma_{\infty}$ , the following relation from (1)

is used:

$$\frac{\gamma}{\gamma_{\infty}} = \left( 1 + \frac{1}{K_2} \right)^{\frac{1}{2}} \left( \frac{1}{1 + \frac{1}{K_2}} \right)^{\frac{1}{2}}$$

Curve 1-8 for any value of  $\gamma_{\infty}$  vs  $K_2$  has been plotted and

$\gamma_{\infty}$  can be obtained directly using the value of  $\gamma$  obtained.

### Thrust Augmentation

The net thrust on a thrust augmentor is due to the difference between the internal and external integrated pressures. The internal integrated pressures is equal to the change in momentum between the bell mouth and the beginning of the mixing length (assuming constant total momentum in the constant area mixing tube length). The sum of the external forces is composed of the normal pressure forces over the bounding surface.

For steady flow from (4)\*

$$PdA - Fdx = d(PA + \rho A v^2) \dots\dots\dots(30)$$

Assuming no friction

$$PdA = d(PA + \rho A v^2) \dots\dots\dots(31)$$

$$\text{Since } \rho = \frac{P}{gRT} \text{ and } M = \frac{v}{\sqrt{\gamma gRT}}$$

(2) becomes

$$\text{Net wall reaction} = PdA = d(PA [1 + \gamma M^2]) \dots\dots\dots(32)$$

Integrating

$$\text{Net wall reaction} = P_2 A_2 (1 + \gamma M_2^2) - P_{2'} A_{2'} (1 + \gamma M_{2'}^2) \dots\dots(33)$$

Since the pressures are measured above absolute zero the above equation must be corrected for external force  $\int_2^2 PdA = P_3(A - A')$  The net thrust on the augmentor is the equal to

$$F = P_2 (A - a)(1 + \gamma M_2^2) - P_{2'} (A' - a)(1 + \gamma M_{2'}^2) + P_3 (A' - A) \dots\dots(34)$$

A further refinement can be made by computing the net thrust on the primary jet and determining the ratio of

Let  $f(x)$  be a function defined on the interval  $[a, b]$ .

Suppose that  $f(x)$  is continuous on  $[a, b]$ .

Then the function  $f(x)$  attains its maximum and minimum values on  $[a, b]$ .

Moreover, if  $f(x)$  is differentiable on  $(a, b)$ , then the maximum and minimum values of  $f(x)$  on  $[a, b]$  must occur at the endpoints  $a$  and  $b$  or at points where  $f'(x) = 0$ .

Let  $f(x)$  be a function defined on the interval  $[a, b]$ .

Suppose that  $f(x)$  is continuous on  $[a, b]$ .

Then the function  $f(x)$  attains its maximum and minimum values on  $[a, b]$ .

$$f(x) = x^2 + 2x + 1 \quad (1)$$

Let  $f(x)$  be a function defined on the interval  $[a, b]$ .

$$f(x) = x^2 + 2x + 1 \quad (2)$$

$$f'(x) = 2x + 2 = 0 \Rightarrow x = -1$$

Let  $f(x)$  be a function defined on the interval  $[a, b]$ .

$$f(x) = x^2 + 2x + 1 \quad (3)$$

Let  $f(x)$  be a function defined on the interval  $[a, b]$ .

$$f(x) = x^2 + 2x + 1 \quad (4)$$

Let  $f(x)$  be a function defined on the interval  $[a, b]$ .

Suppose that  $f(x)$  is continuous on  $[a, b]$ .

$$f(x) = x^2 + 2x + 1 \quad (5)$$

Let  $f(x)$  be a function defined on the interval  $[a, b]$ .

$$f(x) = x^2 + 2x + 1 \quad (6)$$

Let  $f(x)$  be a function defined on the interval  $[a, b]$ .

the two. However, in this thesis only a quantitative measurement of the effect of the various design parameters was desired so such a comparison was deemed not necessary.



TABLE I

Values used in computing curves.

$\frac{P_o}{P}$	M	M	$\frac{P_o}{P}$	$\frac{W\sqrt{T_o}}{AP}$	$\frac{1+\gamma M^2}{M \sqrt{\frac{\gamma g}{R} (1+\frac{\gamma-1}{2} M^2)}}$	$\frac{A}{A_o}$
1.0001	.01197	.17	1.0203	.1565	6.6474	
1.0002	.01699	.18	1.0228	.1658	6.3040	3.2797
1.0003	.02075	.19	1.0253	.1750	6.0021	
1.0004	.02392	.20	1.0282	.1843	5.7290	2.9650
1.0005	.02681	.21	1.0310	.1936	5.4834	
1.0006	.02934	.22	1.0342	.2029	5.2613	2.7090
1.0007	.03166	.23	1.0374	.2122	5.0603	
1.0008	.03383	.24	1.0407	.2216	4.8752	2.4968
1.0009	.03593	.25	1.0443	.2309	4.7085	
1.001	.03785	.26	1.0480	.2403	4.5539	2.3183
1.002	.05347	.27	1.0518	.2496	4.4138	
1.003	.06556	.28	1.0558	.2590	4.2833	2.1666
1.004	.07567	.29	1.0599	.2684	4.1629	
1.005	.08458	.30	1.0643	.2778	4.0517	2.0360
1.006	.09264	.31	1.0696	.2873	3.9473	
1.007	.10005	.32	1.0732	.2967	3.8519	1.9227
1.008	.10695	.33	1.0780	.3062	3.7620	
1.009	.11341	.34	1.0830	.3157	3.6784	1.8236
1.010	.11947	.35	1.0881	.3252	3.601	
1.011	.12533	.36	1.0933	.3347	3.528	1.7365
1.012	.13088	.37	1.0988	.3442	3.460	
1.013	.13621	.38	1.1044	.3538	3.396	1.6591
1.014	.14131	.39	1.1103	.3633	3.337	
1.015	.14626	.40	1.1161	.3730	3.279	1.5908
1.016	.15103	.41		.3826	3.227	
1.017	.15564	.42		.3922	3.177	
1.018	.16013	.43		.4019	3.130	
1.019	.16449	.44		.4116	3.086	
1.020	.16873	.45		.4213	3.044	
		.46		.4310	3.009	
		.47		.4408	2.968	
		.48		.4506	2.933	
		.49		.4604	2.899	
		.50		.4702	2.868	

Table 1. Values of the function  $f(x)$  for various values of  $x$ .

$x$	$f(x)$	$f(x)$	$f(x)$	$f(x)$	$f(x)$	$f(x)$
0.00	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.01	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
0.02	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996
0.03	0.9991	0.9991	0.9991	0.9991	0.9991	0.9991
0.04	0.9984	0.9984	0.9984	0.9984	0.9984	0.9984
0.05	0.9975	0.9975	0.9975	0.9975	0.9975	0.9975
0.06	0.9964	0.9964	0.9964	0.9964	0.9964	0.9964
0.07	0.9951	0.9951	0.9951	0.9951	0.9951	0.9951
0.08	0.9936	0.9936	0.9936	0.9936	0.9936	0.9936
0.09	0.9919	0.9919	0.9919	0.9919	0.9919	0.9919
0.10	0.9900	0.9900	0.9900	0.9900	0.9900	0.9900
0.11	0.9879	0.9879	0.9879	0.9879	0.9879	0.9879
0.12	0.9856	0.9856	0.9856	0.9856	0.9856	0.9856
0.13	0.9831	0.9831	0.9831	0.9831	0.9831	0.9831
0.14	0.9804	0.9804	0.9804	0.9804	0.9804	0.9804
0.15	0.9775	0.9775	0.9775	0.9775	0.9775	0.9775
0.16	0.9744	0.9744	0.9744	0.9744	0.9744	0.9744
0.17	0.9711	0.9711	0.9711	0.9711	0.9711	0.9711
0.18	0.9676	0.9676	0.9676	0.9676	0.9676	0.9676
0.19	0.9639	0.9639	0.9639	0.9639	0.9639	0.9639
0.20	0.9600	0.9600	0.9600	0.9600	0.9600	0.9600
0.21	0.9559	0.9559	0.9559	0.9559	0.9559	0.9559
0.22	0.9516	0.9516	0.9516	0.9516	0.9516	0.9516
0.23	0.9471	0.9471	0.9471	0.9471	0.9471	0.9471
0.24	0.9424	0.9424	0.9424	0.9424	0.9424	0.9424
0.25	0.9375	0.9375	0.9375	0.9375	0.9375	0.9375
0.26	0.9324	0.9324	0.9324	0.9324	0.9324	0.9324
0.27	0.9271	0.9271	0.9271	0.9271	0.9271	0.9271
0.28	0.9216	0.9216	0.9216	0.9216	0.9216	0.9216
0.29	0.9159	0.9159	0.9159	0.9159	0.9159	0.9159
0.30	0.9100	0.9100	0.9100	0.9100	0.9100	0.9100
0.31	0.9039	0.9039	0.9039	0.9039	0.9039	0.9039
0.32	0.8976	0.8976	0.8976	0.8976	0.8976	0.8976
0.33	0.8911	0.8911	0.8911	0.8911	0.8911	0.8911
0.34	0.8844	0.8844	0.8844	0.8844	0.8844	0.8844
0.35	0.8775	0.8775	0.8775	0.8775	0.8775	0.8775
0.36	0.8704	0.8704	0.8704	0.8704	0.8704	0.8704
0.37	0.8631	0.8631	0.8631	0.8631	0.8631	0.8631
0.38	0.8556	0.8556	0.8556	0.8556	0.8556	0.8556
0.39	0.8479	0.8479	0.8479	0.8479	0.8479	0.8479
0.40	0.8400	0.8400	0.8400	0.8400	0.8400	0.8400
0.41	0.8319	0.8319	0.8319	0.8319	0.8319	0.8319
0.42	0.8236	0.8236	0.8236	0.8236	0.8236	0.8236
0.43	0.8151	0.8151	0.8151	0.8151	0.8151	0.8151
0.44	0.8064	0.8064	0.8064	0.8064	0.8064	0.8064
0.45	0.7975	0.7975	0.7975	0.7975	0.7975	0.7975
0.46	0.7884	0.7884	0.7884	0.7884	0.7884	0.7884
0.47	0.7791	0.7791	0.7791	0.7791	0.7791	0.7791
0.48	0.7696	0.7696	0.7696	0.7696	0.7696	0.7696
0.49	0.7599	0.7599	0.7599	0.7599	0.7599	0.7599
0.50	0.7500	0.7500	0.7500	0.7500	0.7500	0.7500



TABLE 2

Values used in computing curves.

M	$P_0/P$	$W\sqrt{T_0}/AP$	$\frac{1 + \gamma M^2}{M \sqrt{\frac{\gamma}{R} (1 + \frac{\gamma - 1}{2} M^2)}}$	M	A/A <sub>0</sub>
.78	1.4931	.7578	2.4396	.392	2
.80	1.5225	.7794	2.4285	.1985	3
.82	1.5532	.8012	2.4189	.1475	4
.84	1.5853	.8231	2.4108	.1170	5
.86	1.6185	.8452	2.4039	.0975	6
.88	1.6531	.8674	2.3983	.083	7
.89	1.6708	.8786	2.3959	.073	8
.90	1.6890	.8898	2.3938	.065	9
.91	1.7073	.9011	2.3917	.0585	10
.92	1.7262	.9125	2.3898	.053	11
.93	1.7453	.9238	2.3885	.0485	12
.94	1.7649	.9352	2.3873	.0415	14
.95	1.7848	.9467	2.3862	.0363	16
.96	1.8051	.9581	2.3855	.0323	18
.97	1.8256	.9697	2.3849	.0290	20
.98	1.8468	.9813	2.3844	.0268	22
.99	1.8681	.9929	2.3839	.0242	24
1.00	1.8899	1.0046	2.3840	.0223	26
1.02	1.9349	1.0281	2.3844	.0207	28
1.04	1.9813	1.0518	2.3852	.0195	30
1.06	2.0295	1.0757	2.3867	.0145	40
1.08	2.0799	1.0998	2.3887	.0117	50
1.10	2.1313	1.1241	2.3912	.0097	60
1.12	2.1849	1.1484	2.3945		
1.14	2.2412	1.1732	2.3976		
1.16	2.2988	1.1982	2.4012		
1.18	2.3584	1.2232	2.4055		

1	1000	1000.0	1000.0	1000.0	1000.0
2	1001	1001.0	1001.0	1001.0	1001.0
3	1002	1002.0	1002.0	1002.0	1002.0
4	1003	1003.0	1003.0	1003.0	1003.0
5	1004	1004.0	1004.0	1004.0	1004.0
6	1005	1005.0	1005.0	1005.0	1005.0
7	1006	1006.0	1006.0	1006.0	1006.0
8	1007	1007.0	1007.0	1007.0	1007.0
9	1008	1008.0	1008.0	1008.0	1008.0
10	1009	1009.0	1009.0	1009.0	1009.0
11	1010	1010.0	1010.0	1010.0	1010.0
12	1011	1011.0	1011.0	1011.0	1011.0
13	1012	1012.0	1012.0	1012.0	1012.0
14	1013	1013.0	1013.0	1013.0	1013.0
15	1014	1014.0	1014.0	1014.0	1014.0
16	1015	1015.0	1015.0	1015.0	1015.0
17	1016	1016.0	1016.0	1016.0	1016.0
18	1017	1017.0	1017.0	1017.0	1017.0
19	1018	1018.0	1018.0	1018.0	1018.0
20	1019	1019.0	1019.0	1019.0	1019.0
21	1020	1020.0	1020.0	1020.0	1020.0
22	1021	1021.0	1021.0	1021.0	1021.0
23	1022	1022.0	1022.0	1022.0	1022.0
24	1023	1023.0	1023.0	1023.0	1023.0
25	1024	1024.0	1024.0	1024.0	1024.0
26	1025	1025.0	1025.0	1025.0	1025.0
27	1026	1026.0	1026.0	1026.0	1026.0
28	1027	1027.0	1027.0	1027.0	1027.0
29	1028	1028.0	1028.0	1028.0	1028.0
30	1029	1029.0	1029.0	1029.0	1029.0
31	1030	1030.0	1030.0	1030.0	1030.0
32	1031	1031.0	1031.0	1031.0	1031.0
33	1032	1032.0	1032.0	1032.0	1032.0
34	1033	1033.0	1033.0	1033.0	1033.0
35	1034	1034.0	1034.0	1034.0	1034.0
36	1035	1035.0	1035.0	1035.0	1035.0
37	1036	1036.0	1036.0	1036.0	1036.0
38	1037	1037.0	1037.0	1037.0	1037.0
39	1038	1038.0	1038.0	1038.0	1038.0
40	1039	1039.0	1039.0	1039.0	1039.0
41	1040	1040.0	1040.0	1040.0	1040.0
42	1041	1041.0	1041.0	1041.0	1041.0
43	1042	1042.0	1042.0	1042.0	1042.0
44	1043	1043.0	1043.0	1043.0	1043.0
45	1044	1044.0	1044.0	1044.0	1044.0
46	1045	1045.0	1045.0	1045.0	1045.0
47	1046	1046.0	1046.0	1046.0	1046.0
48	1047	1047.0	1047.0	1047.0	1047.0
49	1048	1048.0	1048.0	1048.0	1048.0
50	1049	1049.0	1049.0	1049.0	1049.0
51	1050	1050.0	1050.0	1050.0	1050.0
52	1051	1051.0	1051.0	1051.0	1051.0
53	1052	1052.0	1052.0	1052.0	1052.0
54	1053	1053.0	1053.0	1053.0	1053.0
55	1054	1054.0	1054.0	1054.0	1054.0
56	1055	1055.0	1055.0	1055.0	1055.0
57	1056	1056.0	1056.0	1056.0	1056.0
58	1057	1057.0	1057.0	1057.0	1057.0
59	1058	1058.0	1058.0	1058.0	1058.0
60	1059	1059.0	1059.0	1059.0	1059.0
61	1060	1060.0	1060.0	1060.0	1060.0
62	1061	1061.0	1061.0	1061.0	1061.0
63	1062	1062.0	1062.0	1062.0	1062.0

Curve 1A  
Mach Number  
vs  
Pressure Ratio  
For a Reversible Change

Pressure Ratio  
P

Mach Number

1.0010  
1.0008  
1.0006  
1.0004  
1.0002  
1.0000

0

0.02

0.04

0.06

0.08

0.10

0.12

0.14

0.16

0.18

0.20

0.22

0.24

0.26

0.28

0.30

0.32

0.34

0.36





Curve I-B

Mach Number

vs

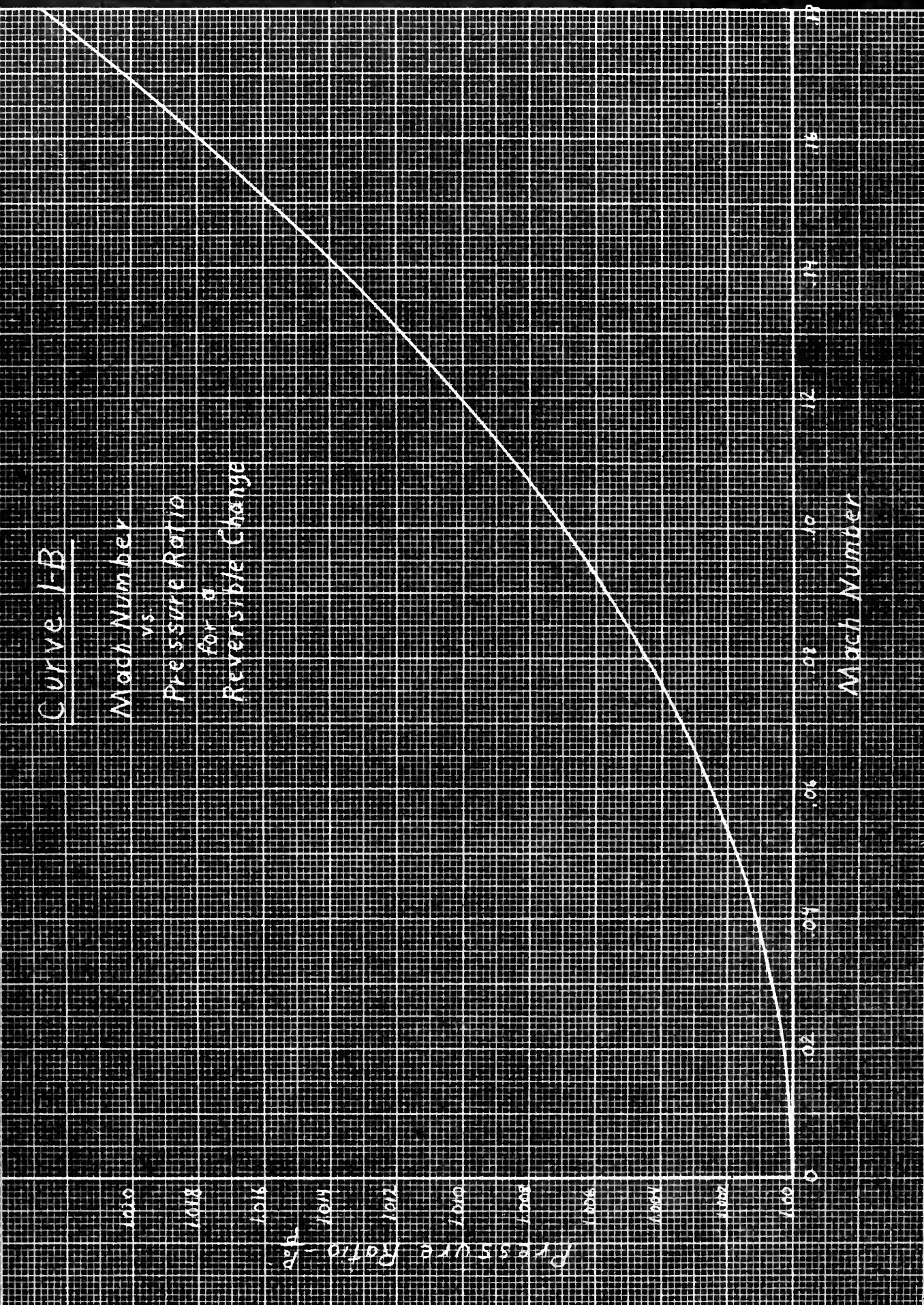
Pressure Ratio

for a

Reversible Change

Pressure Ratio

Mach Number





# Curve 1-C

Mach Number

vs.

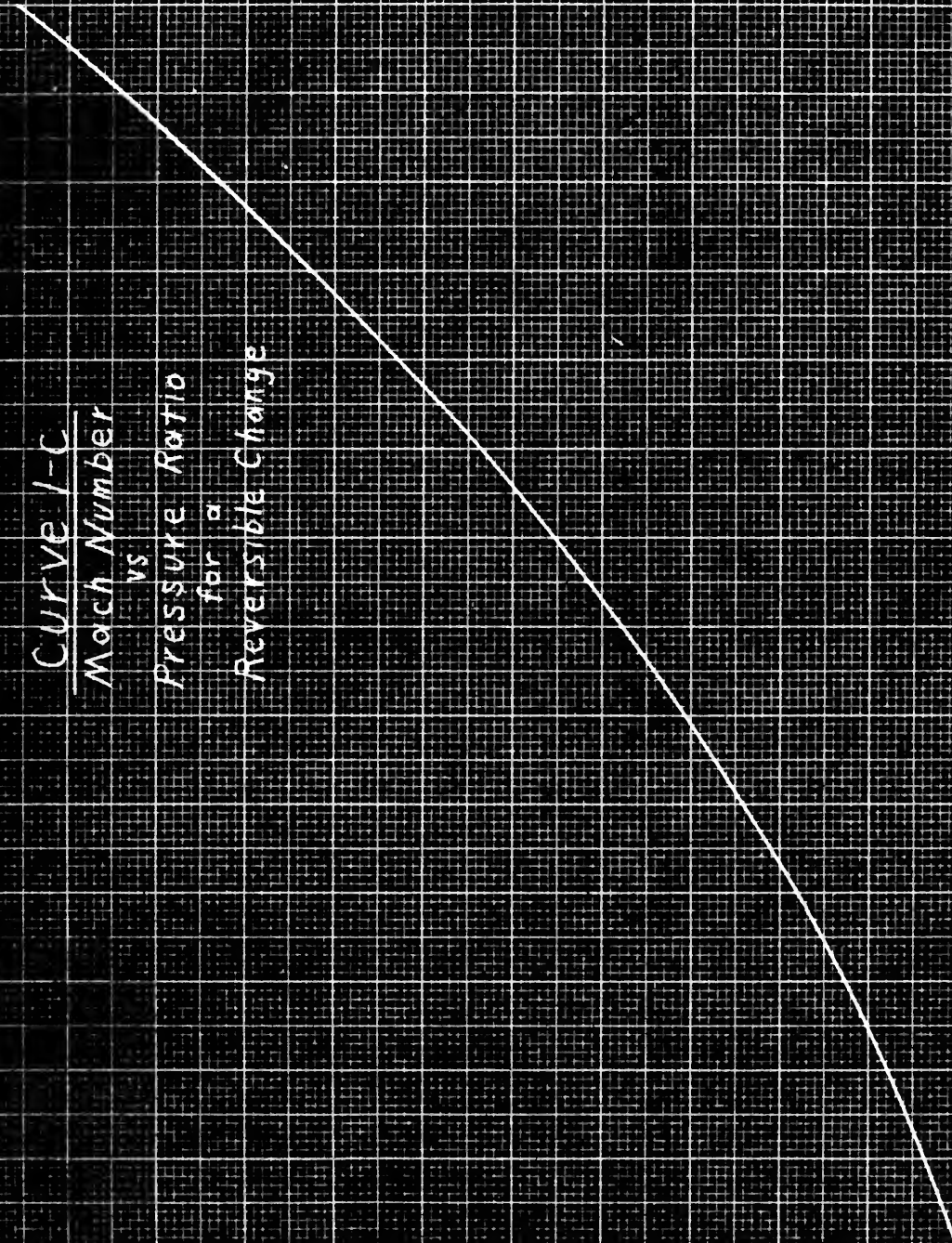
Pressure Ratio

for a

Reversible Change

Pressure Ratio -  $P_0/P$

Mach Number







# Curve 1-D

Mach Number  
vs.

Pressure Ratio

for a

Reversible Change

1.90

1.86

1.82

1.78

1.74

1.70

1.66

1.62

1.58

1.54

1.50

80

82

84

86

88

90

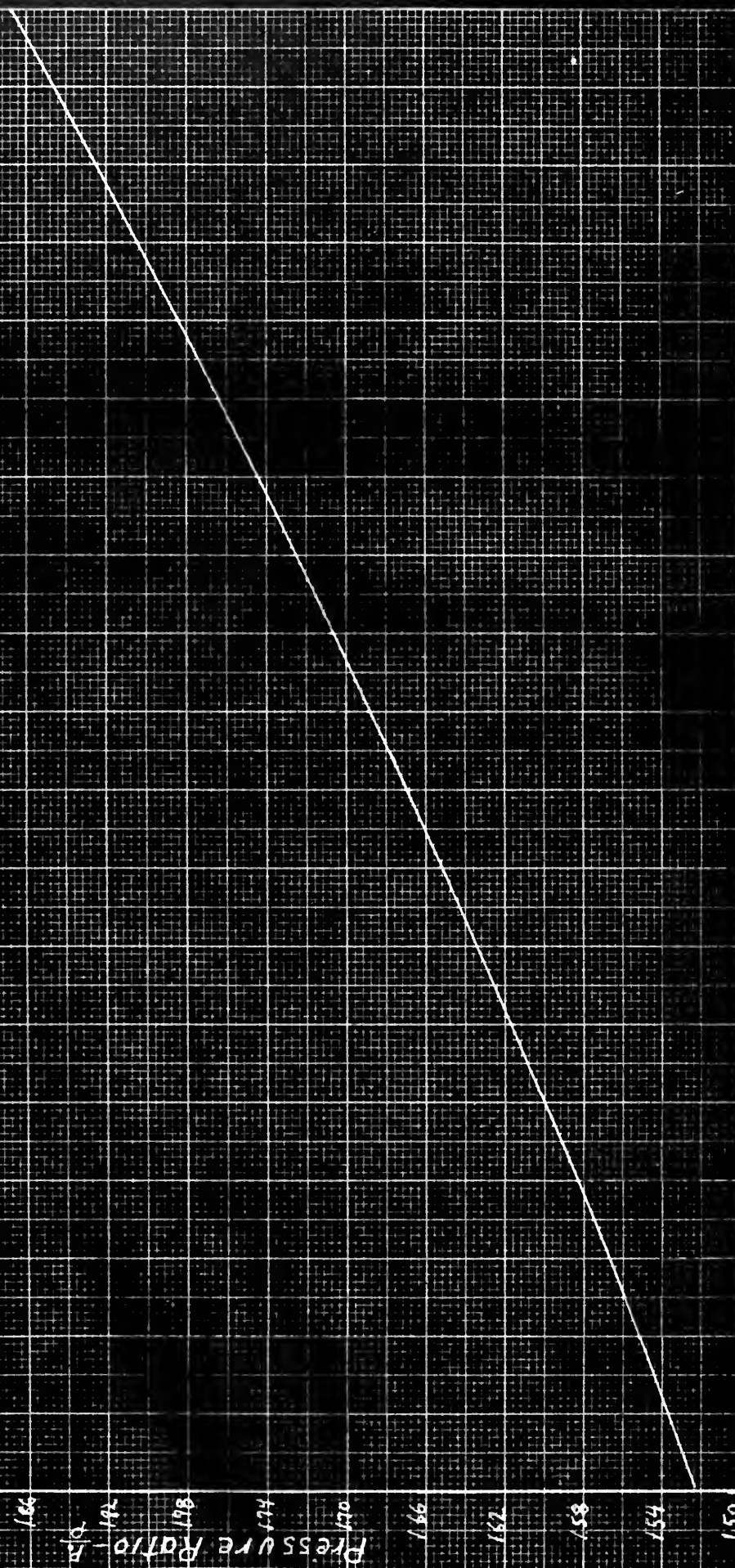
92

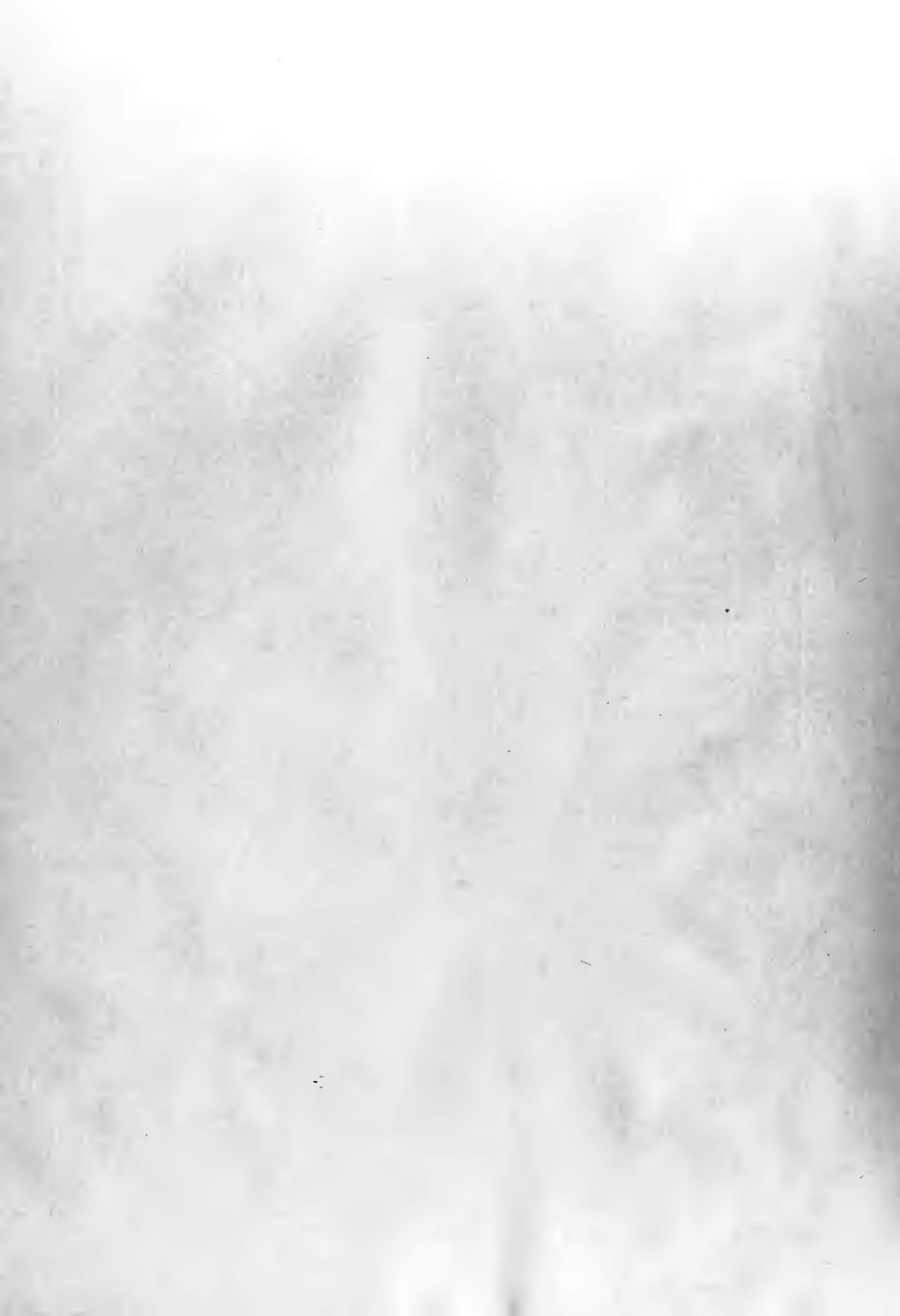
94

96

98

Mach Number





CURVE 1-E  
Mach Number  
vs  
Pressure Ratio  
for  
Reversible Change

Pressure Ratio -  $P_2/P_1$

Mach Number

2.30

2.20

2.10

2.00

1.90

1.80

1.98

1.00

1.02

1.04

1.06

1.08

1.10

1.12

1.14

1.16





Curve 1-F  
Area Ratio  
VS  
Mach Number  
For a  
Reversible Change  
Area at  $M=1.0$   
Equals  
Unity

Values of Area Ratio

3.5

3.0

2.5

2.0

1.5

16

20

24

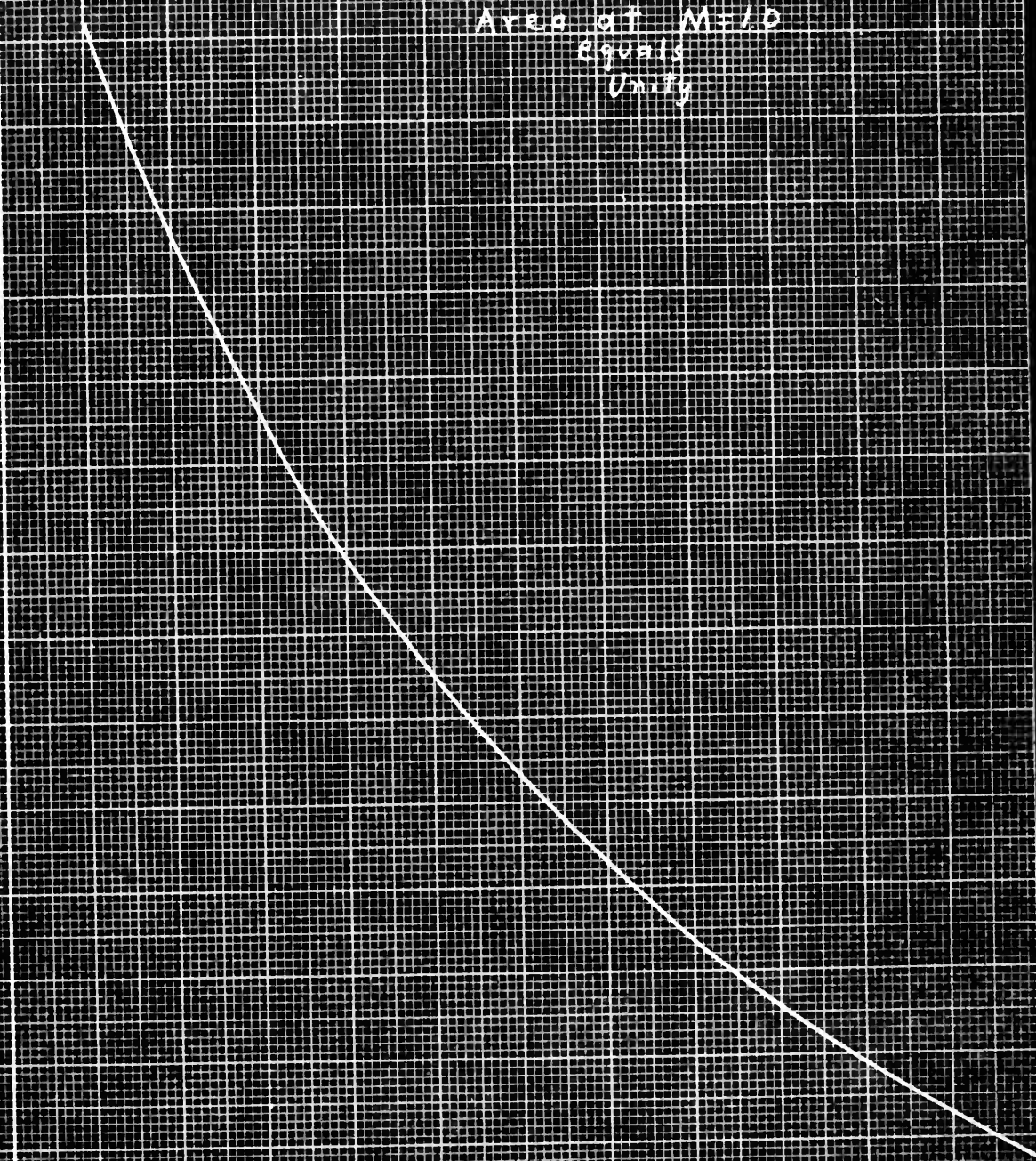
28

32

36

40

Mach Number

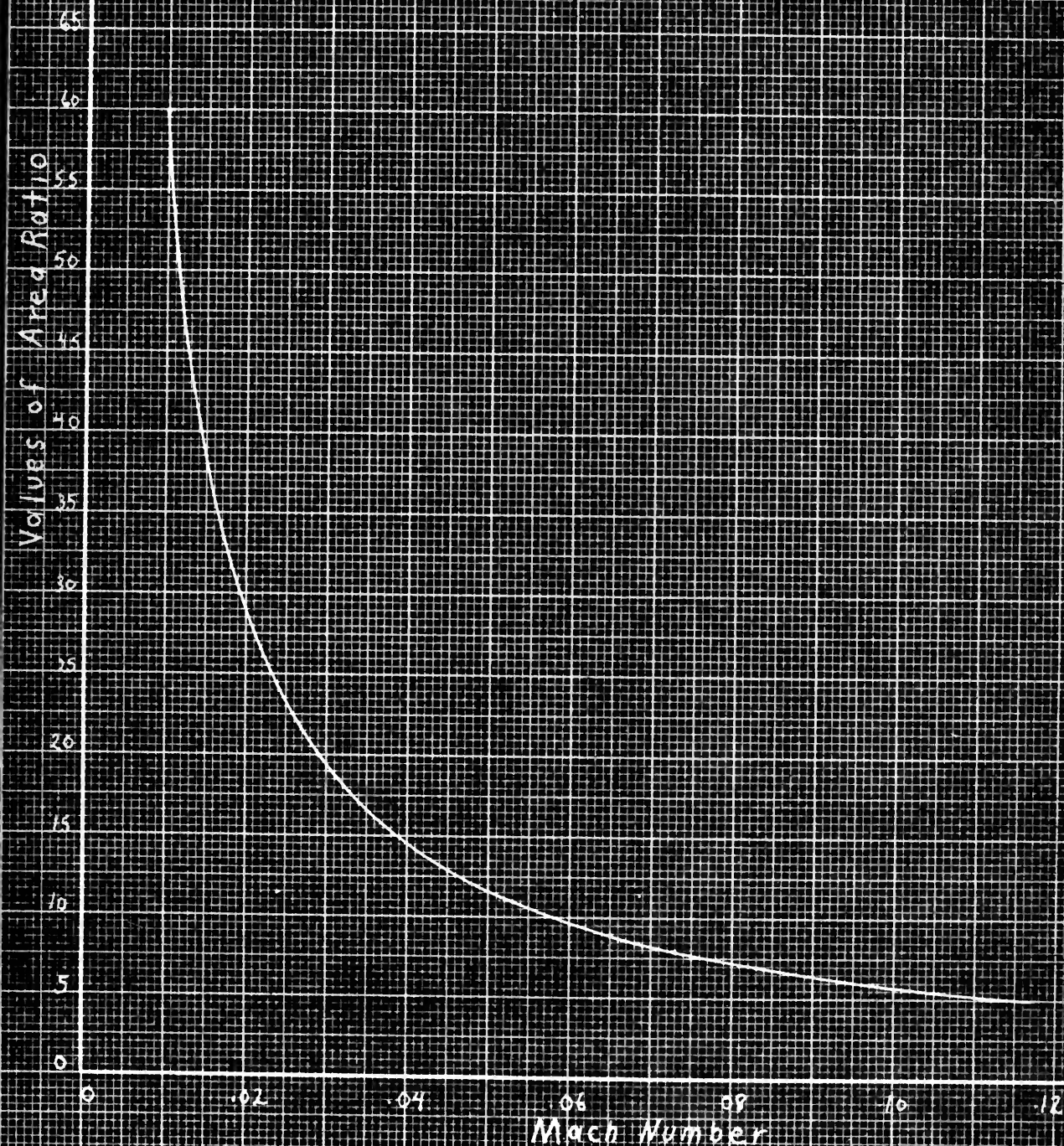




Curve I-G

Area Ratio vs Mach Number  
for a Reversible Change

Area at  $M=1.0$   
equals unity

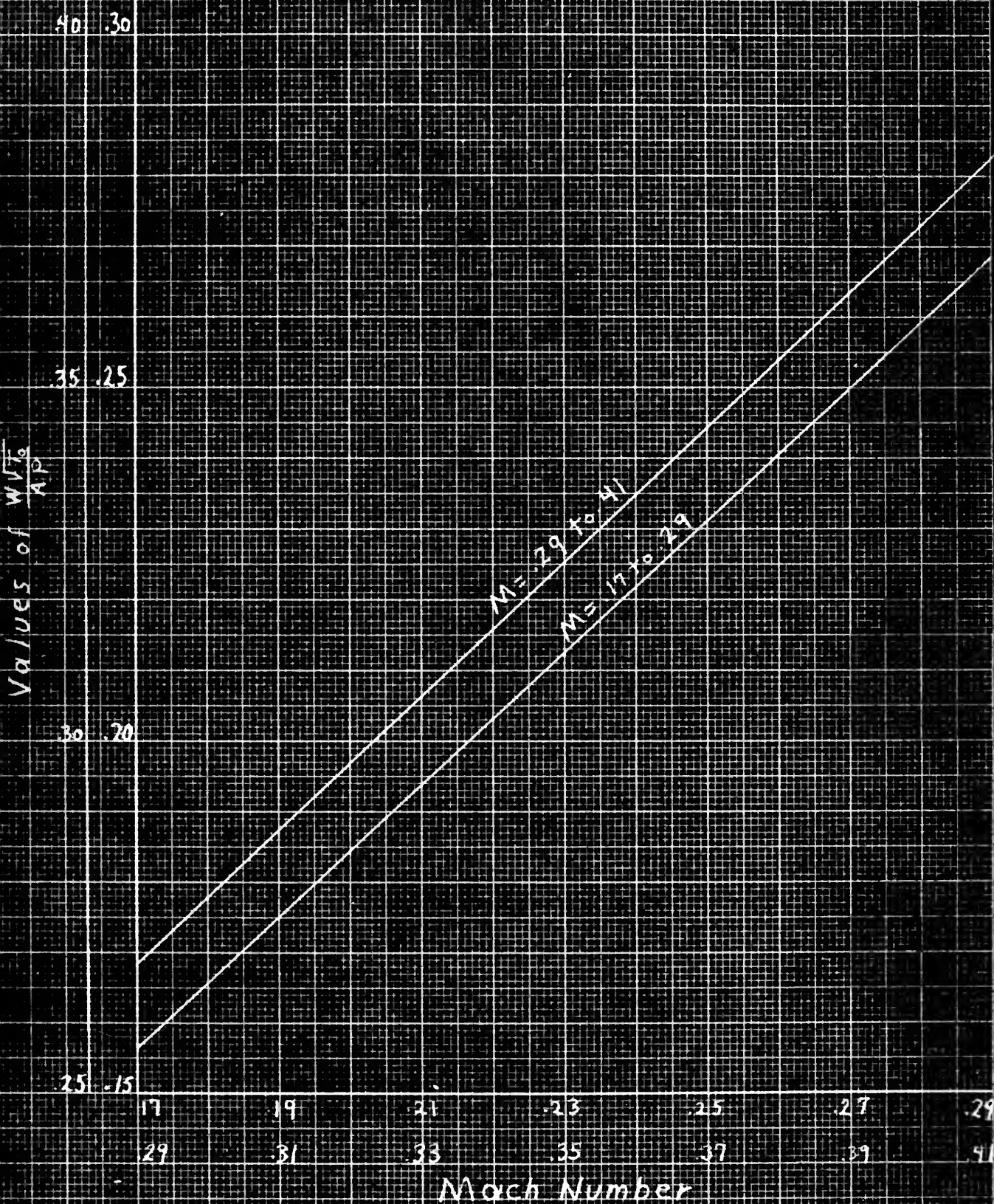






# Curve 1-H

$\frac{WFE}{PA}$  vs Mach Number





Curve I-I  
 $\frac{W}{A} \text{ vs Mach Number}$   
 $\frac{AP}{AP}$

Values of  $\frac{W}{A}$

Mach Number

48

46

44

42

40

38

41

42

43

44

45

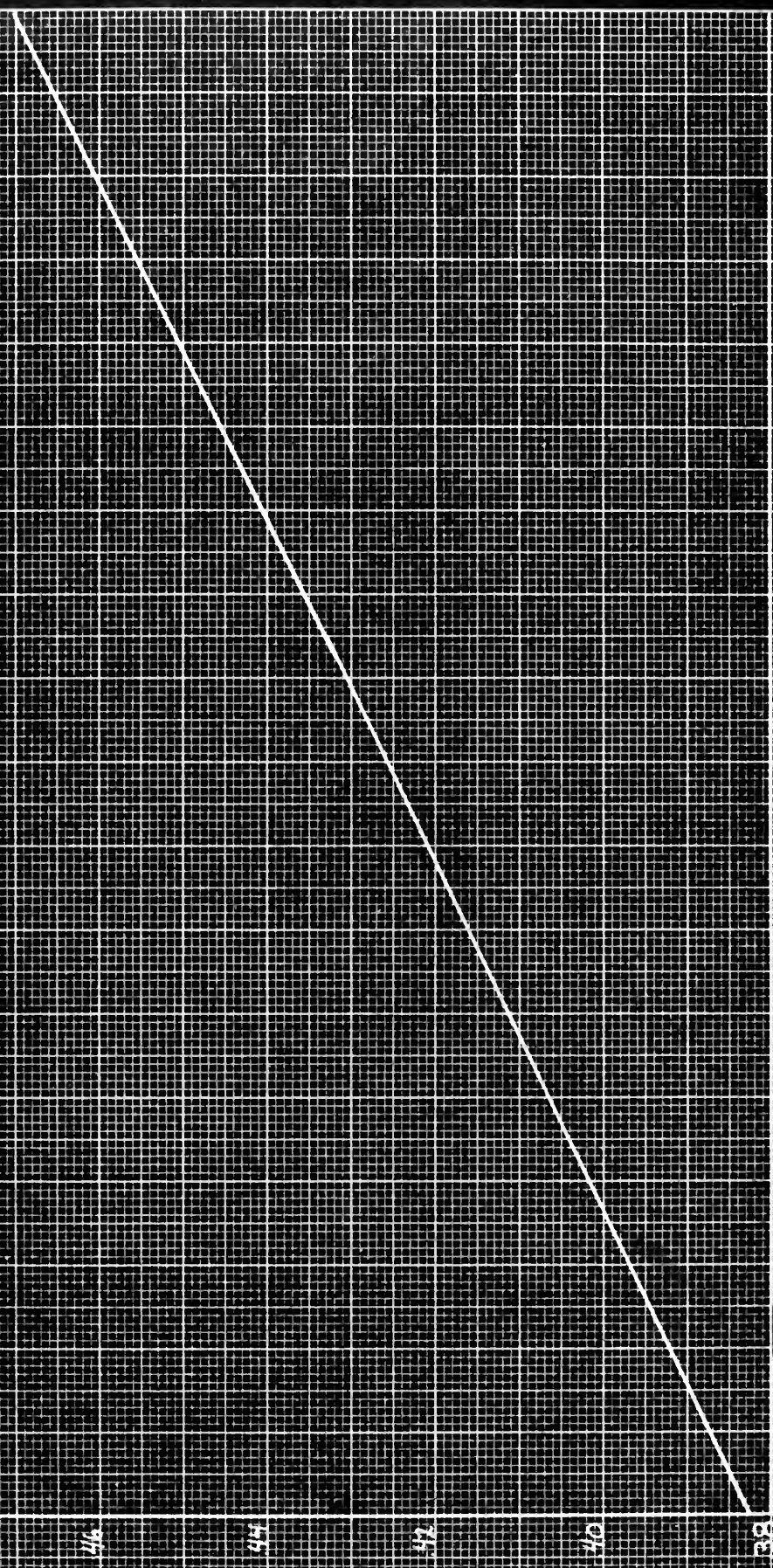
46

47

48

49

50

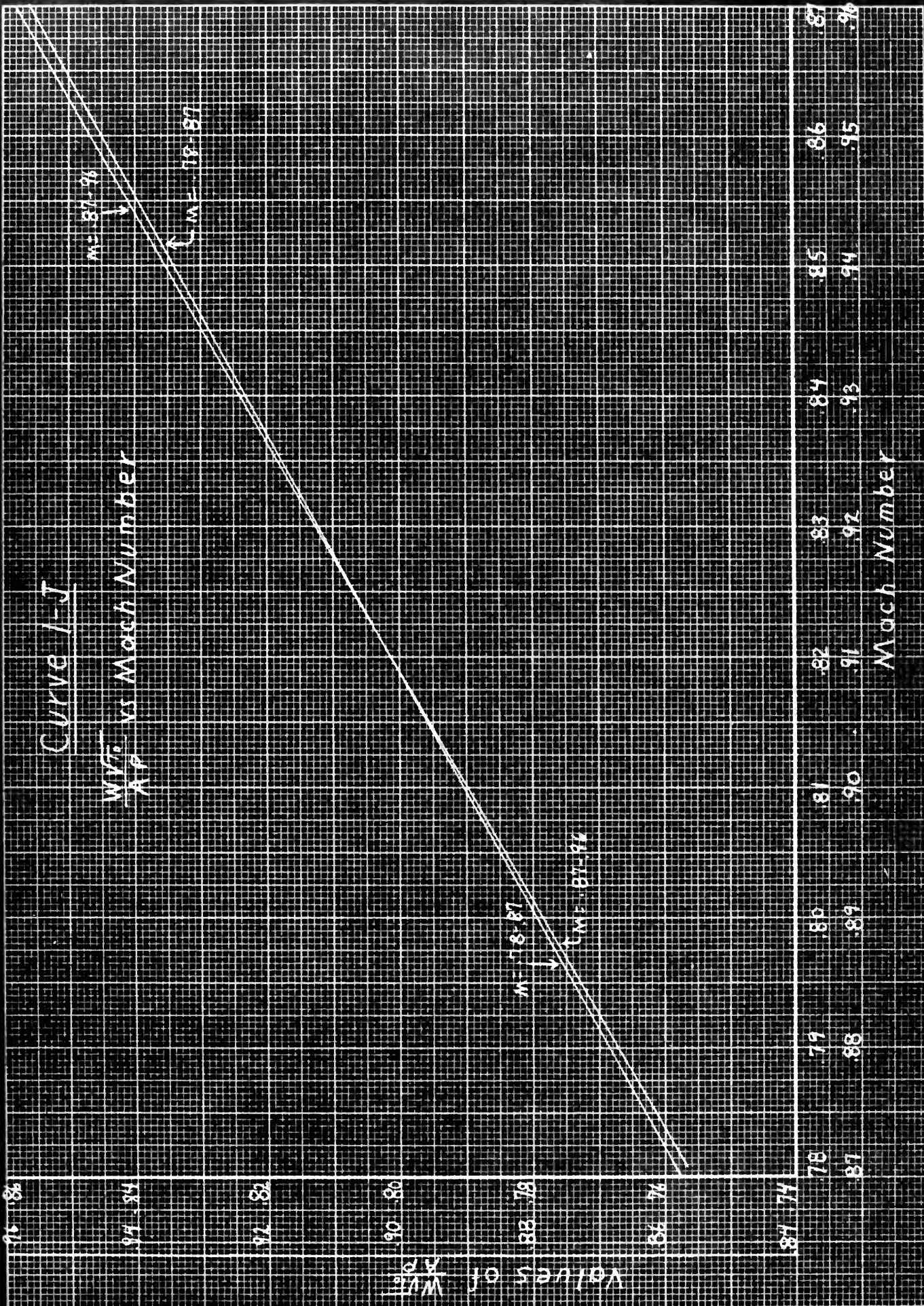






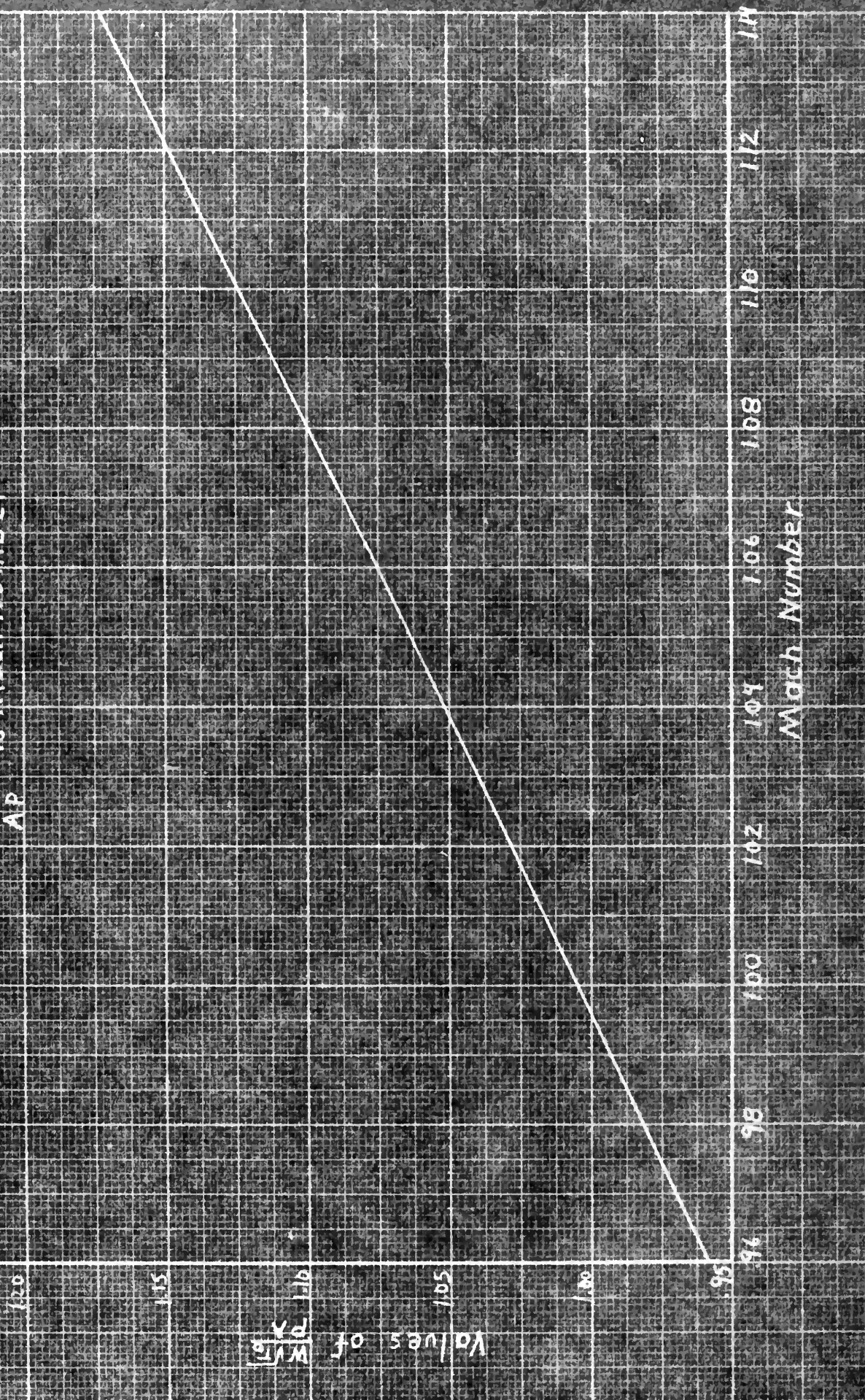
# Curve I-J

$\frac{WV_0}{A_P}$  vs Mach Number

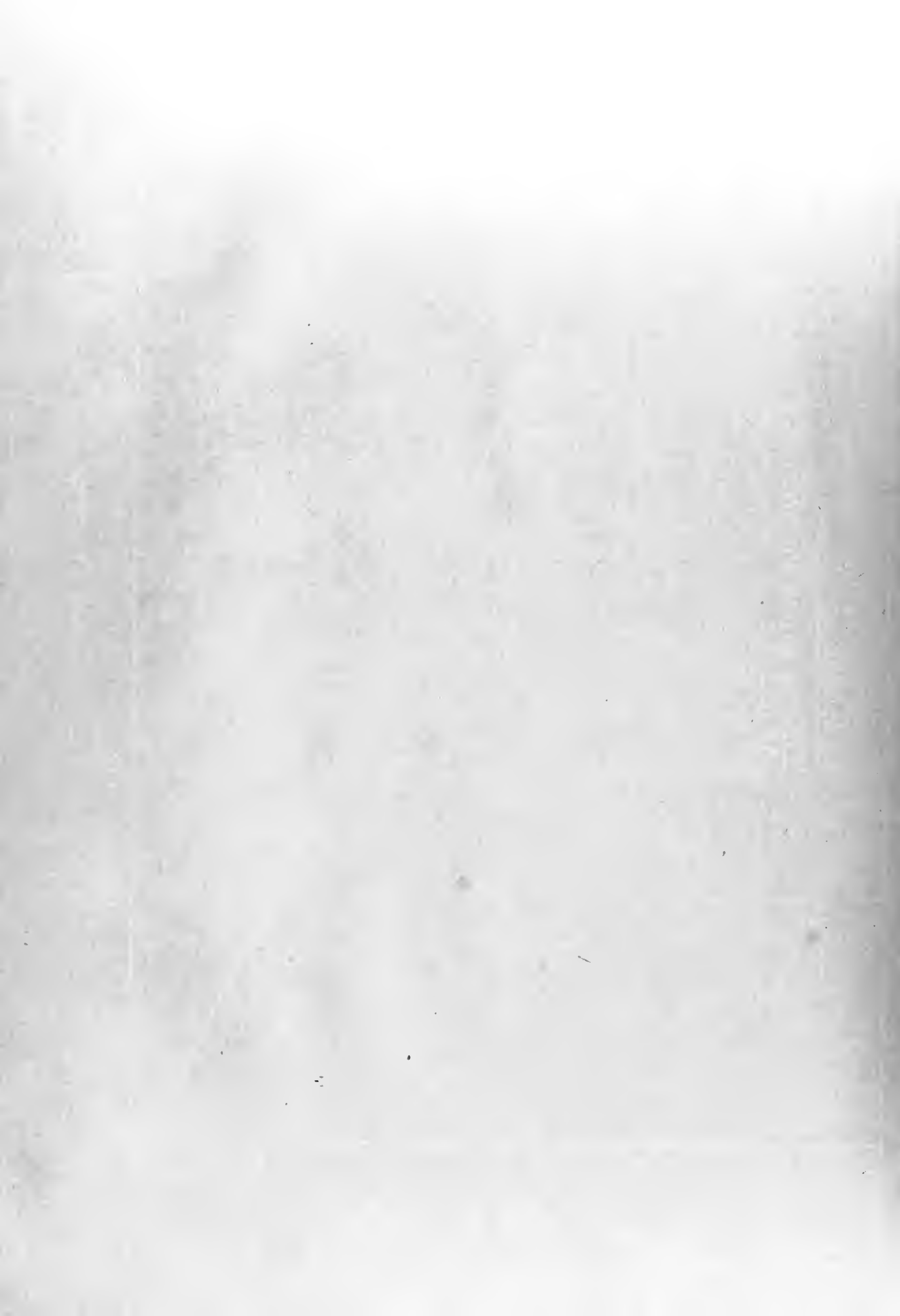




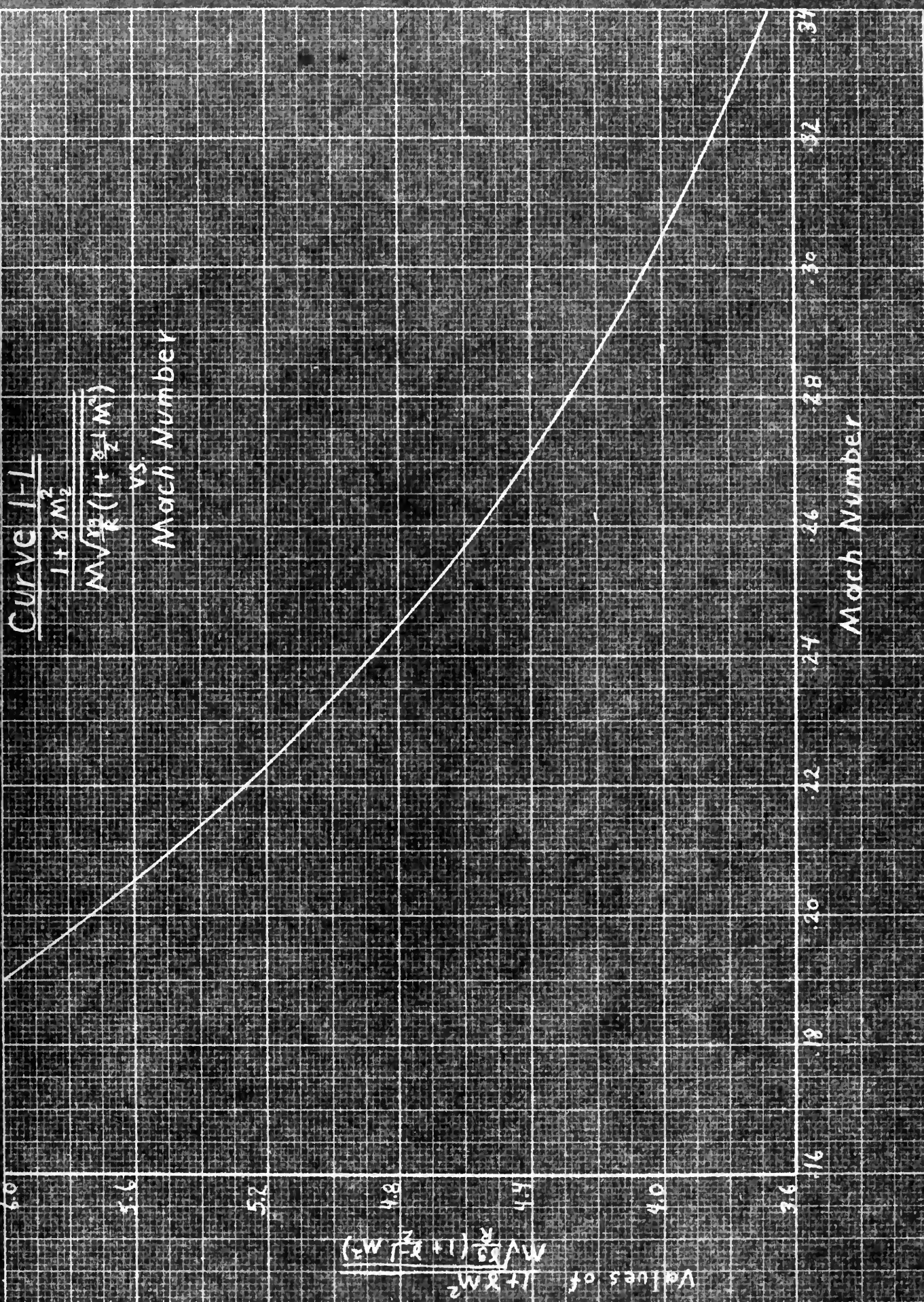
Curve 1-K  
 $\frac{W\sqrt{A}}{A P}$  vs Mach Number







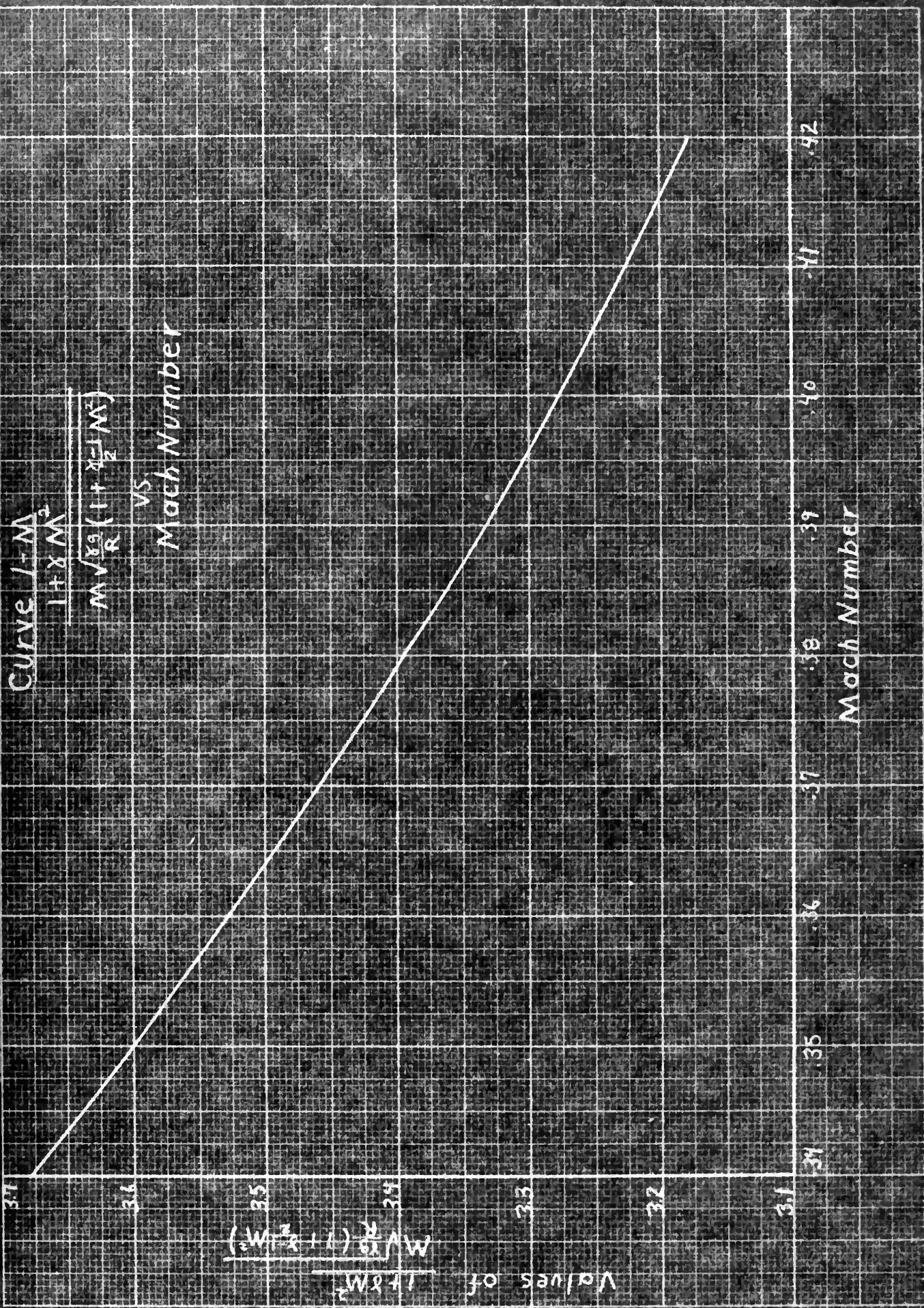








Curve  $\frac{1-M}{1+\gamma M^2}$   
 $\frac{M \sqrt{\frac{\gamma}{\gamma-1}} (1 + \frac{\gamma-1}{2} M^2)}{R}$   
 VS  
 Mach Number

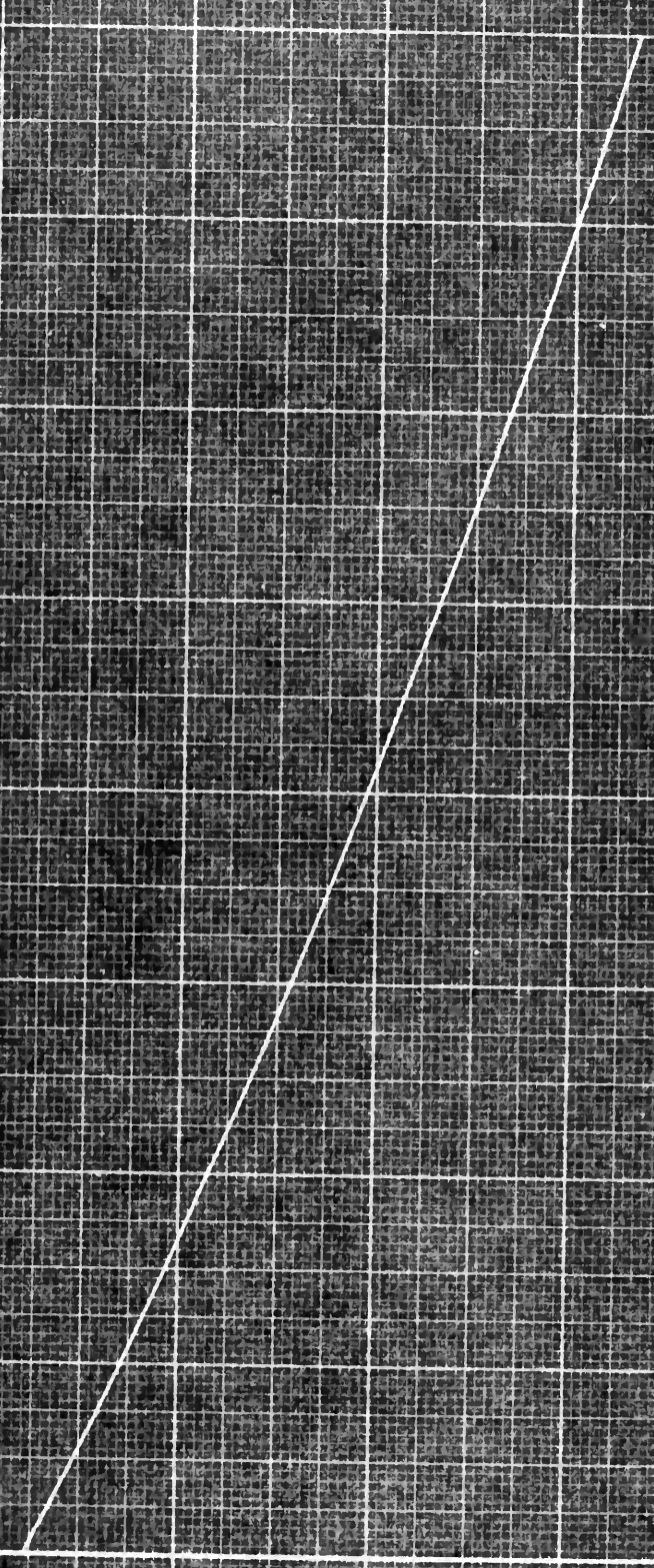






Curve  $\frac{1-N}{1+\gamma M^2}$   
 $\frac{M \sqrt{\frac{\gamma}{\gamma+1}}}{\frac{\gamma}{\gamma+1} (1 + \frac{\gamma-1}{2} M^2)}$   
 vs.  
 Mach Number

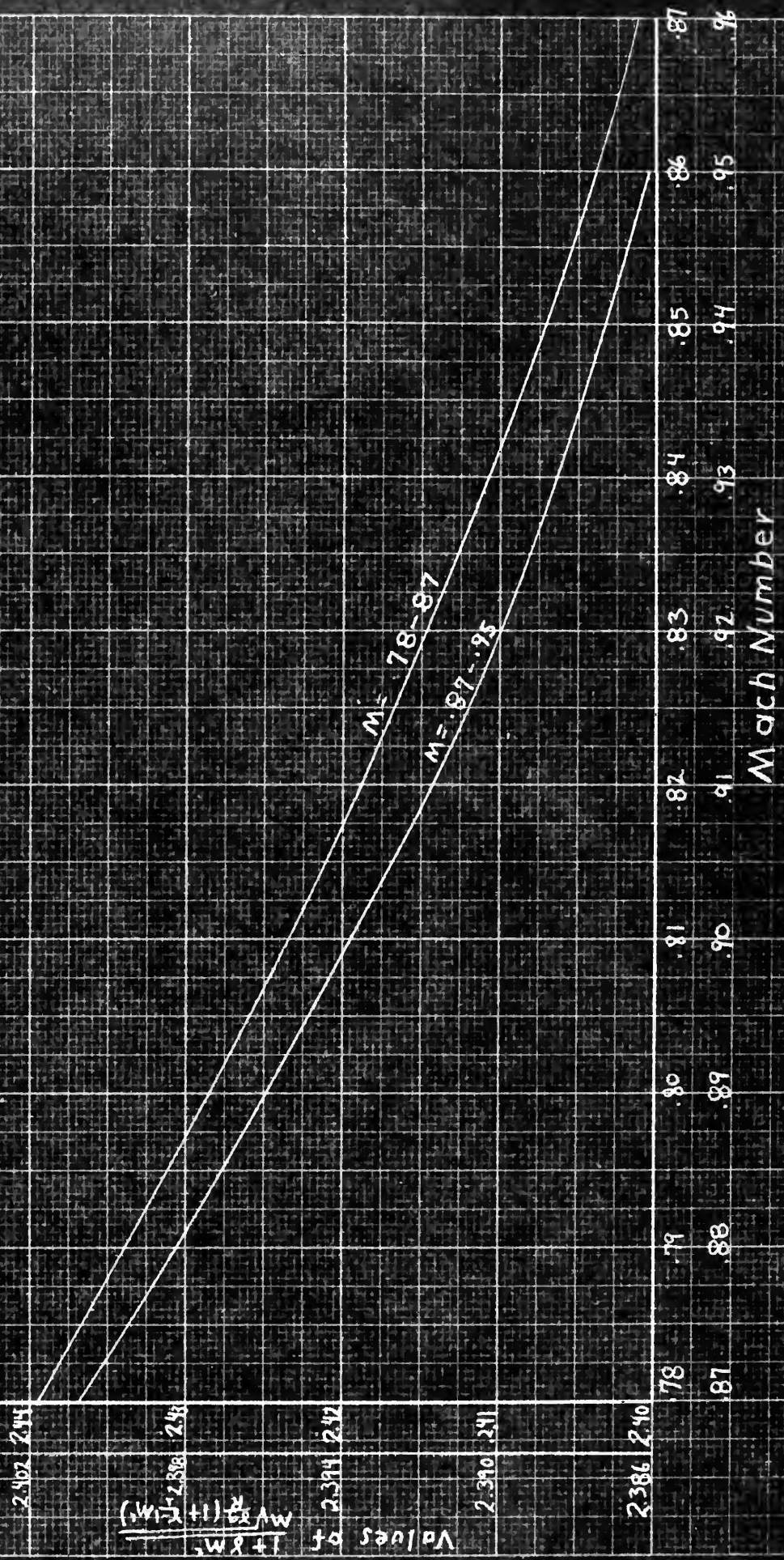
Values of  $\frac{1-N}{1+\gamma M^2}$   
 $\frac{M \sqrt{\frac{\gamma}{\gamma+1}}}{\frac{\gamma}{\gamma+1} (1 + \frac{\gamma-1}{2} M^2)}$



0.42 0.43 0.44 0.45 0.46 0.47 0.48 0.49 0.50  
 Mach Number



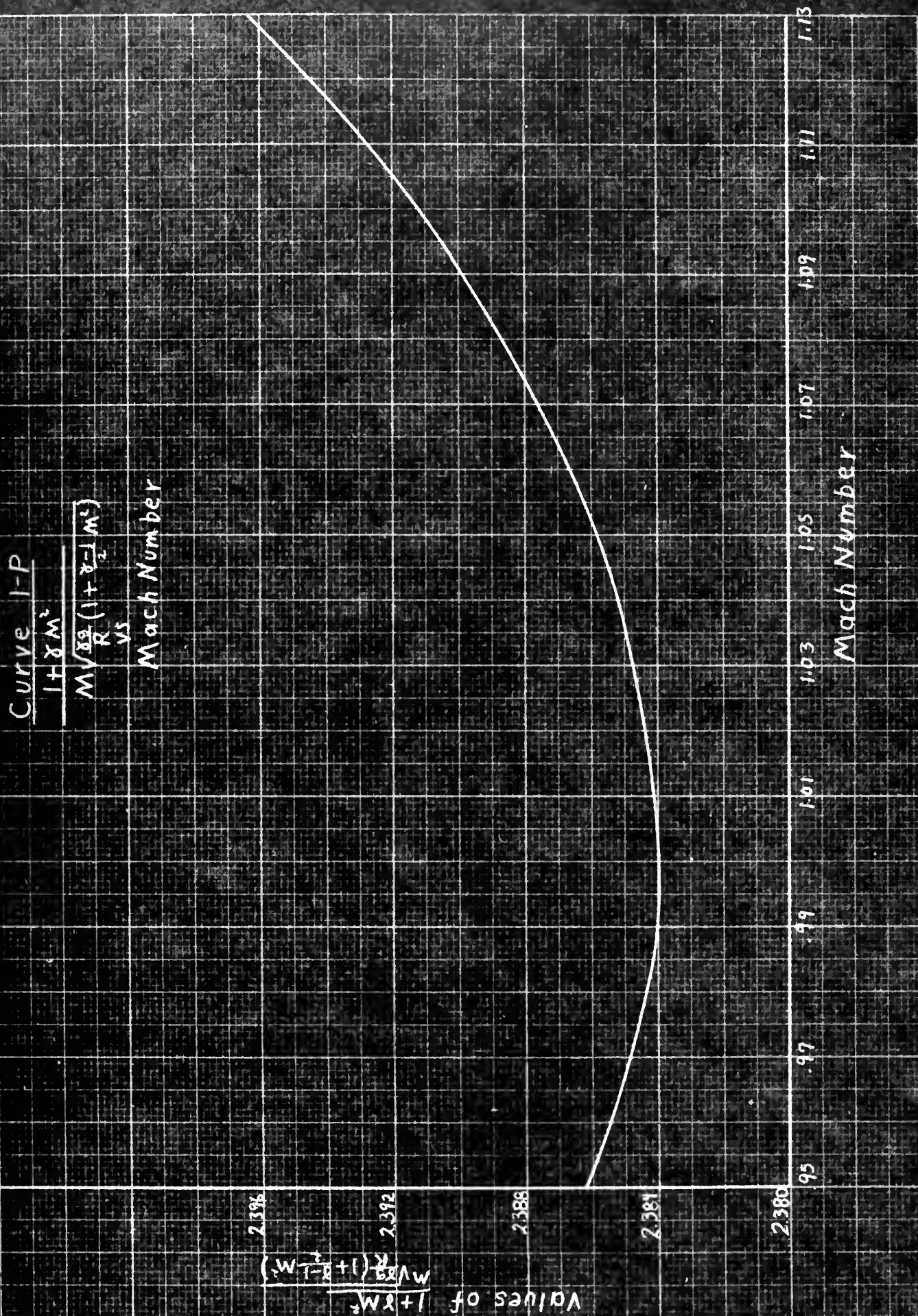
Curve  $t=0$   
 $\frac{1}{1+\gamma M^2}$   
 $\frac{M \sqrt{\frac{\gamma}{\gamma+1}} (1+\gamma M^2)^{-\frac{\gamma}{\gamma+1}}}{\gamma}$   
 vs.  
 Mach Number



Values of  
 $\frac{1}{1+\gamma M^2}$   
 $\frac{M \sqrt{\frac{\gamma}{\gamma+1}} (1+\gamma M^2)^{-\frac{\gamma}{\gamma+1}}}{\gamma}$









## PART II

Calculation Procedure

In a thrust augmentor if the mixed streams do not exhaust at atmospheric pressure, there will be energy loss due to "under-expansion" or "over-expansion". Consequently, if it assumed that the exhaust is at atmospheric, then under static conditions  $P_{o2}/P_1 = P_3/P_1$ , where  $P_2 = P_1$ .

With the above relation, it is possible to solve the thrust augmentor problem. It is not practicable to solve directly. For any given set of physical dimensions, total pressure ratio, and temperature, there is only one  $M_2$  which will be a solution. By assuming an  $M_2$  and using equations (13) and (16),  $M_3$  can be computed. With  $M_1$ ,  $M_2$ ,  $M_3$ , and  $w_2/w_1$ , equation (26) can be used and  $P_3/P_1$  calculated. By using various values of  $M_2$  and solving for  $P_3/P_1$ , a plot of  $P_3/P_1$  and  $P_{o2}/P_1$  vs  $M$  can be made. The point of intersection of these two curves is the solution.

After a solution has been obtained the net thrust can be calculated from equation (34):

$$F = P_2 (A-a)(1 + \gamma M_2^2) - P_2 (A'-a)(1 + \gamma M_2'^2) + P_3 (A'-A)$$

There are four fundamental variables in the thrust augmentation problem. These are  $T_{o1}/T_{o2}$ ,  $P_{o2}/P_{o1}$ ,  $A/a$  and  $A'/A$ , (see figure 1 for nomenclature). Since the permutations and combinations of these four variables would be practically endless, it was decided to use three values of temperature ratio, 2, 3, and 4, and three values of pressure ratio 1.5, 1.7

... it is not possible to solve the  
 system of equations (1) and (2) for the  
 variables  $x_1, x_2, \dots, x_n$  and  $y_1, y_2, \dots, y_n$ .  
 It is known that the system is not solvable, then the

$$\text{matrix condition } \Delta = \Delta_1 + \Delta_2 + \dots + \Delta_n = 0.$$

Let the above relation be possible to solve the

linear equations (1) and (2). It is not possible to solve  
 the system (1) and (2) for the variables  $x_1, x_2, \dots, x_n$  and  
 $y_1, y_2, \dots, y_n$  and the system (1) and (2) is not solvable.  
 It is known that the system is not solvable, then the

$$\text{matrix condition } \Delta = \Delta_1 + \Delta_2 + \dots + \Delta_n = 0.$$

Let the above relation be possible to solve the  
 linear equations (1) and (2). It is not possible to solve  
 the system (1) and (2) for the variables  $x_1, x_2, \dots, x_n$  and  
 $y_1, y_2, \dots, y_n$  and the system (1) and (2) is not solvable.  
 It is known that the system is not solvable, then the

matrix condition  $\Delta = \Delta_1 + \Delta_2 + \dots + \Delta_n = 0$  is not solvable.

Let the above relation be possible to solve the

$$\text{matrix condition } \Delta = \Delta_1 + \Delta_2 + \dots + \Delta_n = 0.$$

Let the above relation be possible to solve the

linear equations (1) and (2). It is not possible to solve  
 the system (1) and (2) for the variables  $x_1, x_2, \dots, x_n$  and  
 $y_1, y_2, \dots, y_n$  and the system (1) and (2) is not solvable.  
 It is known that the system is not solvable, then the  
 matrix condition  $\Delta = \Delta_1 + \Delta_2 + \dots + \Delta_n = 0$  is not solvable.  
 Let the above relation be possible to solve the  
 linear equations (1) and (2). It is not possible to solve  
 the system (1) and (2) for the variables  $x_1, x_2, \dots, x_n$  and  
 $y_1, y_2, \dots, y_n$  and the system (1) and (2) is not solvable.  
 It is known that the system is not solvable, then the  
 matrix condition  $\Delta = \Delta_1 + \Delta_2 + \dots + \Delta_n = 0$  is not solvable.

and 1.9. Since the value of  $M_2$  depends on temperature ratio, pressure ratio and  $A/a$  each of the preceding nine possible combinations of pressure and temperature ratios was computed using six values of area ratio, 5, 10, 12.5, 15, 17.5 and 20. "a" was assumed unity. Values above 20 were not used because of the physical difficulties of such a design. Using the above combinations 54 values of  $M_2$  were calculated. These are plotted on curves (2A) (2B) (2C). With these curves, intermediate solutions can be obtained. Since the curves are very similar, interpolation and double interpolation can be used to obtain any solution in the range of values used.

It is interesting to note that while these calculations were primarily for thrust augmentation, the curves obtained are very useful in theoretical design of a constant area air ejector. Values of  $W_2/W_1$ ,  $M_1$ , and  $M_3$  are not plotted but are included in tables (3) and (4) for reference in case the preceding calculations were to be used for air ejector problems.

After values of  $M_2$  had been calculated, the only remaining variable was  $A'/A$ .  $A'/A$  was then varied from 2 to 20 in six steps 2, 4, 8, 12, 16 and 20. In calculation of net thrust  $P_{o2} = P_3$  was assumed to be 14.7. Net thrust was then calculated from equation (34)

$$F = P_2 (A-a)(1 + \gamma M_2^2) - P_2 (A'-a)(1 + \gamma M_2'^2) + P_3 (A'-A)$$

Results are tabulated in tables 5, 6, and 7.





### Sample Calculation.

Since the pages of calculation were repetitive and voluminous only sample calculations are included. The original calculations will be retained in the possession of the author if reference to them is desired.

### Calculation of $M_2$

From equations (13) and (26) a table was set up.

The following calculations were for  $P_{o1}/P_{o2} = 1.9$ ,

$T_{o2}/T_{o1} = 3.0$ ,  $A/a = 17.5$

Detailed steps:

- (1)  $M_2$  was assumed
- (2)  $P_{o2}/P_1$  was obtained from curves 1-B and 1-C
- (3)  $P_{o1}/P_1$  was obtained from relation  $P_{o1}/P_1 = (P_{o2}/P_1)(P_{o1}/P_{o2})$
- (4)  $M_1$  was obtained from curve 1-D and 1-E
- (5)  $W_1 \sqrt{T_{o1}}/aP_1$  was obtained from curves 1-J and 1-K
- (6)  $W_2 \sqrt{T_{o2}}/(A-a) P_2$  was obtained from curves 1-H and 1-I
- (7)  $W_2/W_1$  was calculated as follows: 
$$\frac{W_2}{W_1} = \sqrt{\frac{T_{o2}}{T_{o1}}} \frac{(A-a)}{a} \frac{f'(M_2)}{f'(M_1)}$$

where  $f'(M_2)$  and  $f'(M_1)$  are the values obtained in (5) and (6).

- (8)  $f(M_1)$  was obtained from curves 1-O and 1-P
- (9)  $f(M_2)$  was obtained from curve 1-L, 1-M, and 1-N.
- (10)  $f(M_3)$  was then calculated using equation (13)
- (11)  $P_3/P_1$  was calculated using equation (26)



original calculations will be repeated in the preparation of the report if necessary to show in detail.

### Calculation of $\beta$

From equations (1b) and (2b) a value for  $\beta$  was obtained.

The following calculations were for  $\beta = 1.0$ .

$$\log \frac{T}{T_0} = 0.0, \quad \log \frac{T}{T_0} = 1.0$$

Notation:  $\beta$

(1)  $\beta$  was assumed

(2)  $\log \frac{T}{T_0}$  was obtained from curves 1-3 and 1-4

$$(3) \log \frac{T}{T_0} \text{ was obtained from relation } \log \frac{T}{T_0} = \left( \log \frac{T}{T_0} \right) \left( \log \frac{T}{T_0} \right)$$

(4)  $\beta$  was obtained from curve 1-5 and 1-6

(5)  $\log \frac{T}{T_0}$  was obtained from curves 1-7 and 1-8

(6)  $\log \frac{T}{T_0}$  was obtained from curves 1-9 and 1-10

$$(7) \log \frac{T}{T_0} \text{ was calculated as follows: } \frac{W}{W_0} = \sqrt{\frac{T_0}{T} \left( \frac{1}{1-\beta} \right) \left( \frac{1}{1-\beta} \right)}$$

where  $T_0$  and  $T_1$  are the values obtained in

(8) and (9)

(10)  $T_0$  was obtained from curves 1-11 and 1-12

(11)  $T_1$  was obtained from curves 1-13, 1-14, and 1-15

(12)  $T_0$  was then calculated using equation (10)

(13)  $T_1$  was calculated using equation (11)

$M_2$	$P_{O_2}/P_1$	$P_{O_1}/P_1$	$M_1$	$W_1 \sqrt{\frac{(x)}{T_{O_1}}} / aP_1$	$W_2 \sqrt{\frac{(y)}{T_{O_2}}} / (A-a)P_2$	$W_2/W_1$	$r(M_1)$	$r(M_2)$
.23	1.0374	1.9711	1.0352	1.0463	.2122	5.7961	2.3849	5.0603
.24	1.0407	1.9773	1.0381	1.0497	.2216	6.0532	2.3850	4.8752
.25	1.0443	1.9842	1.0410	1.0530	.2309	6.2667	2.3852	4.7085
(1)	(2)	(3)	(4)	(5)	(6)			
$1 + W_2/W_1$	$1 + W_2/W_1$	$T_{O_2}/T_{O_1}$	$\sqrt{(3)}$	$W_2/W_1 \sqrt{T_{O_2}/T_{O_1}}$	$r(M_2)$	$(5) + r(M_1)$		
6.7961	2.9320	19.9262	4.4634	16.9337	19.3186			
7.0532	3.0111	21.1777	4.6018	16.9816	19.3666			
7.2667	3.0889	22.4461	4.7377	17.0357	19.4209			
(7)	(8)	(9)	(10)	(11)	(12)	(13)		
$r(M_3) = (6)/(4)$	$M_3$	$W_3 \sqrt{\frac{(9)}{T_{O_3}}} / aP_3$	$\sqrt{(3)}$	$W_2/W_1 \sqrt{T_{O_2}/T_{O_1}}$	$(11)/(y)$	$1/(x)$		
4.328	.2763	.2554	4.4639	3.3464	15.7700	.9557		
4.208	.2858	.2644	4.6018	3.4833	15.7189	.9527		
4.099	.2954	.2734	4.7377	3.6181	15.6696	.9497		
(14)	(15)							
$(12) + (13)$	$(9) \times (14)$	$P_3/P_1 = (10)/(15)$						
16.7257	4.2717	1.0450						
16.6716	4.4080	1.0440						
16.6193	4.5437	1.0427						

These values of  $P_3/P_1$  when plotted vs  $M_2$  intersects with the plot of

$$P_{O_2}/P_1 \text{ at } M_2 = .247$$



### Sample Calculation of Thrust Augmentation

Using the same conditions as in the calculation of  $M_2$ , thrust augmentation per square inch of primary jet area is calculated as follows:

$A'/A$	$M_2$	$A-a/A_0$	$A'-a/A-a$	$A'-a/A_0$	$M_{2'}$	$P_0/P_{2'}$	$\frac{14.7}{P_0/P_{2'}}$
2	.247	2.426	2.061	5.00	.1168	1.0096	14.5602
4	"	"	4.182	10.1	.0581	1.0024	14.6648
8	"	"	8.424	20.4	.0285	1.00056	14.6918
12	"	"	12.667	30.7	.0190	1.00025	14.6963
16	"	"	16.909	41.0	.0140	1.00014	14.6979
20	"	"	21.152	51.3	.0114	1.00009	14.6987

$1 + \gamma M_2^2$	(1) $(A' - a)(1 + \gamma M_{2'}^2)(P_{2'})$	(2) $P_3(A' - A) \frac{14.7}{P_0/P_2}$	$1 + \gamma M_2^2$
1.01903	504.468	257.25	14.0913
1.00471	1016.637	771.75	"
1.00113	2044.468	1800.75	"
1.00050	3073.062	2829.75	"
1.00027	4101.821	3858.75	"
1.00018	5130.769	4887.75	"

$$(A-a)(P_2)(1 + \gamma M_2^2) \quad \text{Augmentation} = (2) + (3) - (1)$$

252.295	5.077
"	7.408
"	8.577
"	8.983
"	9.224
"	9.276

% Augmentation of  $A'/A = 20$

54.7  
79.9  
92.5  
96.8  
99.4



TABLE 3

## Results

A/a	$P_{O_2}/P_{O_1}$	$T_{O_1}/T_{O_2}$	$W_2/W_1$	$M_3$	$M_2$	$P_0/P_2$
5.0	1.5	2.0	1.9108	.3996	.3035	1.066
10.0	"	"	3.5520	.2980	.2443	1.042
12.5	"	"	4.2498	.2715	.2273	1.0366
15.0	"	"	4.8106	.2483	.2100	1.0310
17.5	"	"	5.3388	.2308	.1970	1.0273
20.0	"	"	5.9433	.2100	.1900	1.0254
5.0	"	3.0	2.2391	.3986	.2883	1.0593
10.0	"	"	4.1661	.2941	.2330	1.0383
12.5	"	"	4.9822	.2670	.2167	1.0331
15.0	"	"	5.6811	.2454	.202	1.0285
17.5	"	"	6.6008	.2272	.189	1.0250
20.0	"	"	6.9225	.2140	.180	1.0230
5.0	"	4.0	2.4093	.3629	.266	1.0502
10.0	"	"	4.6403	.2921	.224	1.0354
12.5	"	"	5.5884	.2659	.210	1.0310
15.0	"	"	6.2899	.2414	.193	1.0262
17.5	"	"	7.1560	.2183	.186	1.0243
20.0	"	"	7.9539	.2163	.179	1.0225
5.0	1.7	2.0	1.8940	.4582	.355	1.0906
10.0	"	"	3.4832	.3409	.282	1.0564
12.5	"	"	4.1369	.3095	.260	1.0479
15.0	"	"	4.7526	.2858	.244	1.0420
17.5	"	"	5.3640	.2697	.233	1.0384
20.0	"	"	5.7665	.2591	.2165	1.0330

1947	1948	1949	1950	1951	1952	1953
100.0	100.0	100.0	100.0	100.0	100.0	100.0
101.0	102.0	103.0	104.0	105.0	106.0	107.0
102.0	104.0	106.0	108.0	110.0	112.0	114.0
103.0	106.0	109.0	112.0	115.0	118.0	121.0
104.0	108.0	112.0	116.0	120.0	124.0	128.0
105.0	110.0	115.0	120.0	125.0	130.0	135.0
106.0	112.0	118.0	124.0	130.0	136.0	142.0
107.0	114.0	121.0	128.0	135.0	142.0	149.0
108.0	116.0	124.0	132.0	140.0	148.0	156.0
109.0	118.0	127.0	136.0	145.0	154.0	163.0
110.0	120.0	130.0	140.0	150.0	160.0	170.0
111.0	122.0	133.0	144.0	155.0	166.0	176.0
112.0	124.0	136.0	148.0	160.0	172.0	182.0
113.0	126.0	139.0	152.0	165.0	178.0	188.0
114.0	128.0	142.0	156.0	170.0	184.0	194.0
115.0	130.0	145.0	160.0	175.0	190.0	200.0
116.0	132.0	148.0	164.0	180.0	196.0	206.0
117.0	134.0	151.0	168.0	185.0	202.0	212.0
118.0	136.0	154.0	172.0	190.0	208.0	218.0
119.0	138.0	157.0	176.0	195.0	214.0	224.0
120.0	140.0	160.0	180.0	200.0	220.0	230.0
121.0	142.0	163.0	184.0	205.0	226.0	236.0
122.0	144.0	166.0	188.0	210.0	232.0	242.0
123.0	146.0	169.0	192.0	215.0	238.0	248.0
124.0	148.0	172.0	196.0	220.0	244.0	254.0
125.0	150.0	175.0	200.0	225.0	250.0	260.0
126.0	152.0	178.0	204.0	230.0	256.0	266.0
127.0	154.0	181.0	208.0	235.0	262.0	272.0
128.0	156.0	184.0	212.0	240.0	268.0	278.0
129.0	158.0	187.0	216.0	245.0	274.0	284.0
130.0	160.0	190.0	220.0	250.0	280.0	290.0
131.0	162.0	193.0	224.0	255.0	286.0	296.0
132.0	164.0	196.0	228.0	260.0	292.0	302.0
133.0	166.0	199.0	232.0	265.0	298.0	308.0
134.0	168.0	202.0	236.0	270.0	304.0	314.0
135.0	170.0	205.0	240.0	275.0	310.0	320.0
136.0	172.0	208.0	244.0	280.0	316.0	326.0
137.0	174.0	211.0	248.0	285.0	322.0	332.0
138.0	176.0	214.0	252.0	290.0	328.0	338.0
139.0	178.0	217.0	256.0	295.0	334.0	344.0
140.0	180.0	220.0	260.0	300.0	340.0	350.0
141.0	182.0	223.0	264.0	305.0	346.0	356.0
142.0	184.0	226.0	268.0	310.0	352.0	362.0
143.0	186.0	229.0	272.0	315.0	358.0	368.0
144.0	188.0	232.0	276.0	320.0	364.0	374.0
145.0	190.0	235.0	280.0	325.0	370.0	380.0
146.0	192.0	238.0	284.0	330.0	376.0	386.0
147.0	194.0	241.0	288.0	335.0	382.0	392.0
148.0	196.0	244.0	292.0	340.0	388.0	398.0
149.0	198.0	247.0	296.0	345.0	394.0	404.0
150.0	200.0	250.0	300.0	350.0	400.0	410.0
151.0	202.0	253.0	304.0	355.0	406.0	416.0
152.0	204.0	256.0	308.0	360.0	412.0	422.0
153.0	206.0	259.0	312.0	365.0	418.0	428.0
154.0	208.0	262.0	316.0	370.0	424.0	434.0
155.0	210.0	265.0	320.0	375.0	430.0	440.0
156.0	212.0	268.0	324.0	380.0	436.0	446.0
157.0	214.0	271.0	328.0	385.0	442.0	452.0
158.0	216.0	274.0	332.0	390.0	448.0	458.0
159.0	218.0	277.0	336.0	395.0	454.0	464.0
160.0	220.0	280.0	340.0	400.0	460.0	470.0
161.0	222.0	283.0	344.0	405.0	466.0	476.0
162.0	224.0	286.0	348.0	410.0	472.0	482.0
163.0	226.0	289.0	352.0	415.0	478.0	488.0
164.0	228.0	292.0	356.0	420.0	484.0	494.0
165.0	230.0	295.0	360.0	425.0	490.0	500.0
166.0	232.0	298.0	364.0	430.0	496.0	506.0
167.0	234.0	301.0	368.0	435.0	502.0	512.0
168.0	236.0	304.0	372.0	440.0	508.0	518.0
169.0	238.0	307.0	376.0	445.0	514.0	524.0
170.0	240.0	310.0	380.0	450.0	520.0	530.0
171.0	242.0	313.0	384.0	455.0	526.0	536.0
172.0	244.0	316.0	388.0	460.0	532.0	542.0
173.0	246.0	319.0	392.0	465.0	538.0	548.0
174.0	248.0	322.0	396.0	470.0	544.0	554.0
175.0	250.0	325.0	400.0	475.0	550.0	560.0
176.0	252.0	328.0	404.0	480.0	556.0	566.0
177.0	254.0	331.0	408.0	485.0	562.0	572.0
178.0	256.0	334.0	412.0	490.0	568.0	578.0
179.0	258.0	337.0	416.0	495.0	574.0	584.0
180.0	260.0	340.0	420.0	500.0	580.0	590.0
181.0	262.0	343.0	424.0	505.0	586.0	596.0
182.0	264.0	346.0	428.0	510.0	592.0	602.0
183.0	266.0	349.0	432.0	515.0	598.0	608.0
184.0	268.0	352.0	436.0	520.0	604.0	614.0
185.0	270.0	355.0	440.0	525.0	610.0	620.0
186.0	272.0	358.0	444.0	530.0	616.0	626.0
187.0	274.0	361.0	448.0	535.0	622.0	632.0
188.0	276.0	364.0	452.0	540.0	628.0	638.0
189.0	278.0	367.0	456.0	545.0	634.0	644.0
190.0	280.0	370.0	460.0	550.0	640.0	650.0
191.0	282.0	373.0	464.0	555.0	646.0	656.0
192.0	284.0	376.0	468.0	560.0	652.0	662.0
193.0	286.0	379.0	472.0	565.0	658.0	668.0
194.0	288.0	382.0	476.0	570.0	664.0	674.0
195.0	290.0	385.0	480.0	575.0	670.0	680.0
196.0	292.0	388.0	484.0	580.0	676.0	686.0
197.0	294.0	391.0	488.0	585.0	682.0	692.0
198.0	296.0	394.0	492.0	590.0	688.0	698.0
199.0	298.0	397.0	496.0	595.0	694.0	704.0
200.0	300.0	400.0	500.0	600.0	700.0	710.0



TABLE 4

Results

A/a	$P_{O_2}/P_{O_1}$	$T_{O_1}/T_{O_2}$	$W_2/W_1$	$M_3$	$M_2$	$P_O/P_2$
5.0	1.7	3.0	2.1841	.4527	.331	1.0786
10.0	"	"	4.0542	.3351	.2665	1.0504
12.5	"	"	4.8686	.3055	.249	1.0440
15.0	"	"	5.6355	.2820	.235	1.039
17.5	"	"	6.2528	.2652	.223	1.0352
20.0	"	"	6.8633	.2480	.210	1.031
5.0	1.7	4.0	2.3749	.4472	.309	1.0682
10.0	"	"	4.5213	.3333	.2565	1.0466
12.5	"	"	5.4147	.3026	.239	1.0404
15.0	"	"	6.3070	.2818	.228	1.0365
17.5	"	"	7.0667	.2632	.216	1.033
20.0	"	"	7.6224	.2440	.2015	1.0286
5.0	1.9	2.0	1.8819	.5027	.399	1.1156
10.0	"	"	3.4361	.3760	.314	1.0762
12.5	"	"	4.0868	.3420	.290	1.0598
15.0	"	"	4.6924	.3167	.272	1.0526
17.5	"	"	5.2314	.2954	.256	1.0466
20.0	"	"	5.7493	.2790	.2435	1.0420
5.0	1.9	3.0	2.1713	.4999	.372	1.0996
10.0	"	"	4.0385	.3727	.298	1.0635
12.5	"	"	4.8158	.3386	.278	1.0545
15.0	"	"	5.5289	.3122	.2607	1.0482
17.5	"	"	6.1967	.2925	.247	1.0432
20.0	"	"	6.8382	.2865	.236	1.0394
5.0	1.9	4.0	2.3488	.4635	.345	1.0856
10.0	"	"	4.4306	.3668	.2835	1.0572
12.5	"	"	5.3144	.3335	.2645	1.0497
15.0	"	"	6.1222	.3082	.2492	1.0446
17.5	"	"	6.9118	.2894	.238	1.040
20.0	"	"	7.6432	.2735	.228	1.0367

Year	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100
1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100	

TABLE 5

## Results

Thrust Augmentation lbs per in<sup>2</sup> of primary jet.

$$P_{o1}/P_{o2} = 1.5$$

$$T_{o1}/T_{o2} = 2.0$$

$\frac{A'}{A}$	$\frac{A}{a} = 5.0$	$\frac{A}{a} = 10.0$	$\frac{A}{a} = 12.5$	$\frac{A}{a} = 15.0$	$\frac{A}{a} = 17.5$	$\frac{A}{a} = 20.0$
2	1.943	2.658	3.064	3.158	3.198	3.449
4	2.730	4.006	4.417	4.612	4.938	5.060
8	3.100	4.609	5.090	5.366	5.558	5.998
12	3.215	4.805	5.341	5.636	5.825	6.271
16	3.285	4.929	5.430	5.748	5.922	6.417
20	3.300	4.954	5.534	5.775	6.020	6.435

$$T_{o1}/T_{o2} = 3.0$$

2	1.771	2.531	2.762	2.953	2.810	3.070
4	2.485	3.670	4.065	4.328	4.269	4.459
8	2.817	4.223	4.696	5.018	5.075	5.343
12	2.927	4.416	4.882	5.217	5.394	5.615
16	2.987	4.512	4.988	5.379	5.501	5.694
20	3.012	4.569	5.040	5.415	5.609	5.775

$$T_{o1}/T_{o2} = 4.0$$

2	1.407	2.333	2.610	2.675	2.897	3.141
4	2.101	3.396	3.804	3.956	4.197	4.530
8	2.407	3.921	4.434	4.549	4.994	5.345
12	2.517	4.090	4.631	4.766	5.243	5.617
16	2.574	4.184	4.717	4.845	5.312	5.696
20	2.587	4.250	4.777	4.914	5.424	5.777

$$0.01 = \frac{1}{100} \times 10^2$$

$0.01 = \frac{1}{100} \times 10^2$	$0.01 = \frac{1}{100} \times 10^2$	$0.01 = \frac{1}{100} \times 10^2$	$0.01 = \frac{1}{100} \times 10^2$	$0.01 = \frac{1}{100} \times 10^2$	$0.01 = \frac{1}{100} \times 10^2$	$\frac{1}{100}$
100.0	100.0	100.0	100.0	100.0	100.0	1
100.1	100.1	100.1	100.1	100.1	100.1	1
100.2	100.2	100.2	100.2	100.2	100.2	1
100.3	100.3	100.3	100.3	100.3	100.3	1
100.4	100.4	100.4	100.4	100.4	100.4	1
100.5	100.5	100.5	100.5	100.5	100.5	1
100.6	100.6	100.6	100.6	100.6	100.6	1
100.7	100.7	100.7	100.7	100.7	100.7	1
100.8	100.8	100.8	100.8	100.8	100.8	1
100.9	100.9	100.9	100.9	100.9	100.9	1

$$0.01 = \frac{1}{100} \times 10^2$$

100.0	100.0	100.0	100.0	100.0	100.0	1
100.1	100.1	100.1	100.1	100.1	100.1	1
100.2	100.2	100.2	100.2	100.2	100.2	1
100.3	100.3	100.3	100.3	100.3	100.3	1
100.4	100.4	100.4	100.4	100.4	100.4	1
100.5	100.5	100.5	100.5	100.5	100.5	1
100.6	100.6	100.6	100.6	100.6	100.6	1
100.7	100.7	100.7	100.7	100.7	100.7	1
100.8	100.8	100.8	100.8	100.8	100.8	1
100.9	100.9	100.9	100.9	100.9	100.9	1

$$0.01 = \frac{1}{100} \times 10^2$$

100.0	100.0	100.0	100.0	100.0	100.0	1
100.1	100.1	100.1	100.1	100.1	100.1	1
100.2	100.2	100.2	100.2	100.2	100.2	1
100.3	100.3	100.3	100.3	100.3	100.3	1
100.4	100.4	100.4	100.4	100.4	100.4	1
100.5	100.5	100.5	100.5	100.5	100.5	1
100.6	100.6	100.6	100.6	100.6	100.6	1
100.7	100.7	100.7	100.7	100.7	100.7	1
100.8	100.8	100.8	100.8	100.8	100.8	1
100.9	100.9	100.9	100.9	100.9	100.9	1

TABLE 6

Results

Thrust Augmentation

$$P_{01}/P_{02} = 1.7$$

$$T_{01}/T_{02} = 2.0$$

$\frac{A'}{A}$	$\frac{A}{a} = 5.0$	$\frac{A}{a} = 10.0$	$\frac{A}{a} = 12.5$	$\frac{A}{a} = 15.0$	$\frac{A}{a} = 17.5$	$\frac{A}{a} = 20.0$
2	2.617	3.675	3.893	4.268	4.519	4.496
4	3.664	5.355	5.725	6.133	6.622	6.634
8	4.128	6.061	6.631	7.160	7.679	7.704
12	4.297	6.314	6.891	7.472	8.037	8.128
16	4.363	6.463	7.071	7.607	8.011	8.299
20	4.418	6.512	7.114	7.750	8.316	8.386

$$T_{01}/T_{02} = 3.0$$

2	2.289	3.269	3.603	3.902	4.135	4.311
4	3.216	4.730	5.344	5.783	6.060	6.270
8	3.639	5.438	6.068	6.619	7.027	7.285
12	3.779	5.657	6.344	6.946	7.349	7.596
16	3.849	5.788	6.505	7.106	7.566	7.762
20	3.880	5.806	6.543	7.217	7.661	7.844

$$T_{01}/T_{02} = 4.0$$

2	2.017	3.051	3.377	3.759	3.883	3.907
4	2.851	4.402	4.929	5.453	5.742	5.726
8	3.212	5.047	5.627	6.310	6.617	6.699
12	3.336	5.271	5.896	6.601	6.953	7.051
16	3.403	5.414	6.029	6.738	7.079	7.153
20	3.435	5.443	6.122	6.807	7.210	7.251

$$U.1 = 10^{10} \sqrt{10^7}$$

$$U.2 = 10^{10} \sqrt{10^7}$$

$U.1 = \frac{1}{2}$	$U.2 = \frac{1}{2}$	$U.3 = \frac{1}{2}$	$U.4 = \frac{1}{2}$	$U.5 = \frac{1}{2}$	$U.6 = \frac{1}{2}$	$\frac{1}{2}$
100.0	100.0	100.0	100.0	100.0	100.0	1
100.0	100.0	100.0	100.0	100.0	100.0	2
100.0	100.0	100.0	100.0	100.0	100.0	3
100.0	100.0	100.0	100.0	100.0	100.0	4
100.0	100.0	100.0	100.0	100.0	100.0	5
100.0	100.0	100.0	100.0	100.0	100.0	6
100.0	100.0	100.0	100.0	100.0	100.0	7
100.0	100.0	100.0	100.0	100.0	100.0	8
100.0	100.0	100.0	100.0	100.0	100.0	9
100.0	100.0	100.0	100.0	100.0	100.0	10

$$U.1 = 10^{10} \sqrt{10^7}$$

100.0	100.0	100.0	100.0	100.0	100.0	1
100.0	100.0	100.0	100.0	100.0	100.0	2
100.0	100.0	100.0	100.0	100.0	100.0	3
100.0	100.0	100.0	100.0	100.0	100.0	4
100.0	100.0	100.0	100.0	100.0	100.0	5
100.0	100.0	100.0	100.0	100.0	100.0	6
100.0	100.0	100.0	100.0	100.0	100.0	7
100.0	100.0	100.0	100.0	100.0	100.0	8
100.0	100.0	100.0	100.0	100.0	100.0	9
100.0	100.0	100.0	100.0	100.0	100.0	10

$$U.1 = 10^{10} \sqrt{10^7}$$

100.0	100.0	100.0	100.0	100.0	100.0	1
100.0	100.0	100.0	100.0	100.0	100.0	2
100.0	100.0	100.0	100.0	100.0	100.0	3
100.0	100.0	100.0	100.0	100.0	100.0	4
100.0	100.0	100.0	100.0	100.0	100.0	5
100.0	100.0	100.0	100.0	100.0	100.0	6
100.0	100.0	100.0	100.0	100.0	100.0	7
100.0	100.0	100.0	100.0	100.0	100.0	8
100.0	100.0	100.0	100.0	100.0	100.0	9
100.0	100.0	100.0	100.0	100.0	100.0	10

TABLE 7

## Results

## Thrust Augmentation

$$P_{01}/P_{02} = 1.9$$

$$T_{01}/T_{02} = 2.0$$

$\frac{A^*}{A}$	$\frac{A}{a} = 5.0$	$\frac{A}{a} = 10.0$	$\frac{A}{a} = 12.5$	$\frac{A}{a} = 15.0$	$\frac{A}{a} = 17.5$	$\frac{A}{a} = 20.0$
2	3.772	4.522	4.826	5.187	5.409	5.681
4	5.319	6.469	7.164	7.602	7.902	8.209
8	5.990	7.401	8.130	8.734	9.139	9.576
12	6.227	7.690	8.495	9.138	9.564	10.028
16	6.342	7.875	8.648	9.343	9.812	10.316
20	6.393	7.952	8.781	9.449	9.936	10.375

$$T_{01}/T_{02} = 3.0$$

2	2.829	4.006	4.587	4.780	5.077	5.313
4	3.992	5.809	6.677	7.056	7.408	7.792
8	4.499	6.673	7.587	8.066	8.577	9.048
12	4.675	6.951	7.896	8.446	8.983	9.489
16	4.760	7.106	8.088	8.623	9.224	9.680
20	4.799	7.196	8.159	8.765	9.276	9.814

$$T_{01}/T_{02} = 4.0$$

2	2.462	3.644	4.068	4.393	4.675	4.926
4	3.457	5.234	5.837	6.363	6.936	7.386
8	3.915	6.081	6.810	7.428	8.011	8.506
12	4.069	6.354	7.104	7.742	8.398	8.880
16	4.145	6.484	7.273	7.958	8.564	9.098
20	4.185	6.578	7.391	8.002	8.682	9.191



TABLE 1.1

$$0.1 = 10^{\frac{1}{10}}$$

$$0.2 = 10^{\frac{2}{10}}$$

$$0.00 = \frac{1}{100} \quad 0.01 = \frac{1}{100} \quad 0.02 = \frac{2}{100} \quad 0.03 = \frac{3}{100} \quad 0.04 = \frac{4}{100} \quad 0.05 = \frac{5}{100}$$

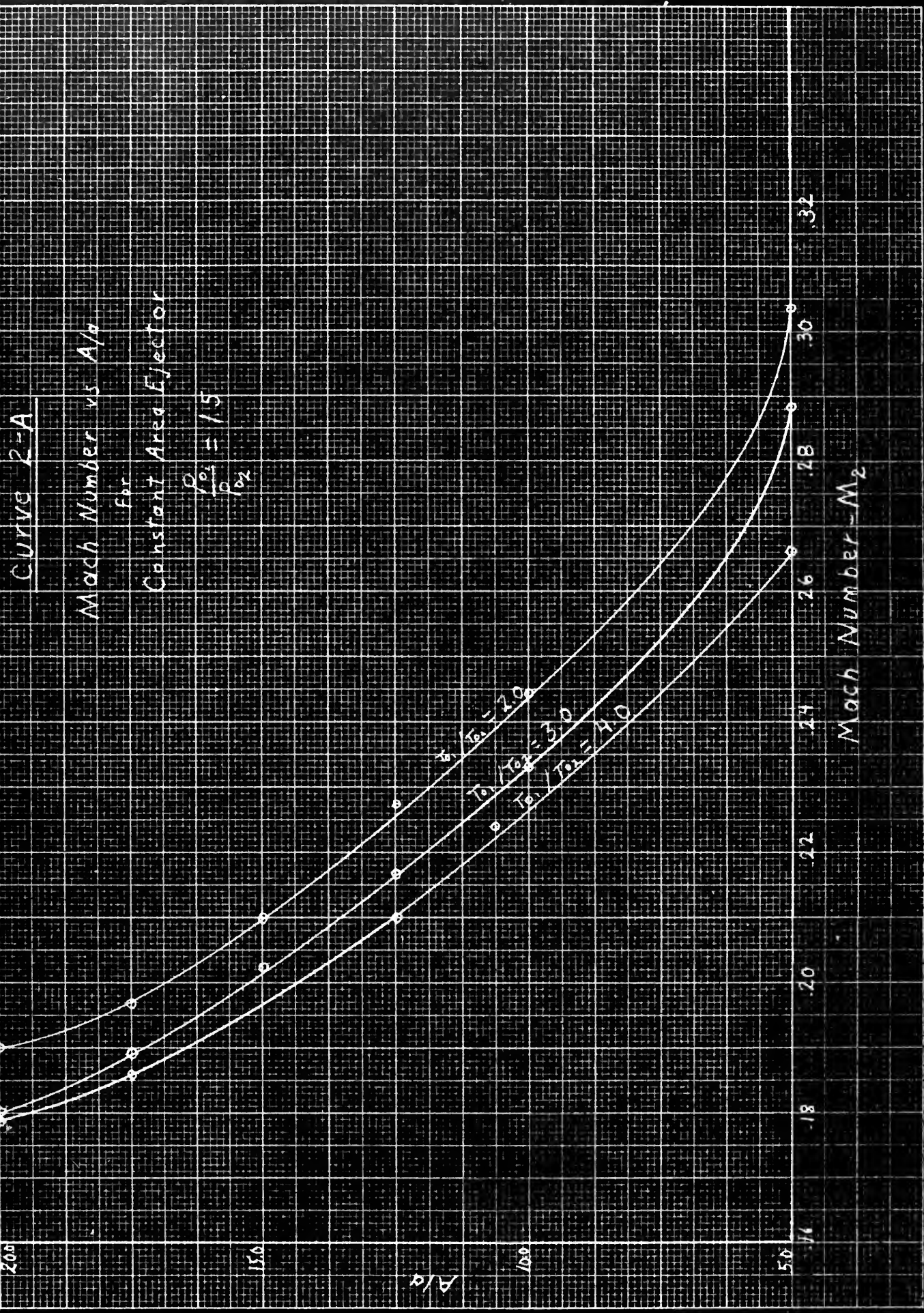
0.00	0.01	0.02	0.03	0.04	0.05	0.06
1.000	1.005	1.010	1.015	1.020	1.025	1.030
1.035	1.040	1.045	1.050	1.055	1.060	1.065
1.070	1.075	1.080	1.085	1.090	1.095	1.100
1.105	1.110	1.115	1.120	1.125	1.130	1.135
1.140	1.145	1.150	1.155	1.160	1.165	1.170

$$0.0 = 10^{\frac{0}{10}}$$

0.00	0.01	0.02	0.03	0.04	0.05	0.06
1.000	1.005	1.010	1.015	1.020	1.025	1.030
1.035	1.040	1.045	1.050	1.055	1.060	1.065
1.070	1.075	1.080	1.085	1.090	1.095	1.100
1.105	1.110	1.115	1.120	1.125	1.130	1.135
1.140	1.145	1.150	1.155	1.160	1.165	1.170

$$0.0 = 10^{\frac{0}{10}}$$

0.00	0.01	0.02	0.03	0.04	0.05	0.06
1.000	1.005	1.010	1.015	1.020	1.025	1.030
1.035	1.040	1.045	1.050	1.055	1.060	1.065
1.070	1.075	1.080	1.085	1.090	1.095	1.100
1.105	1.110	1.115	1.120	1.125	1.130	1.135
1.140	1.145	1.150	1.155	1.160	1.165	1.170

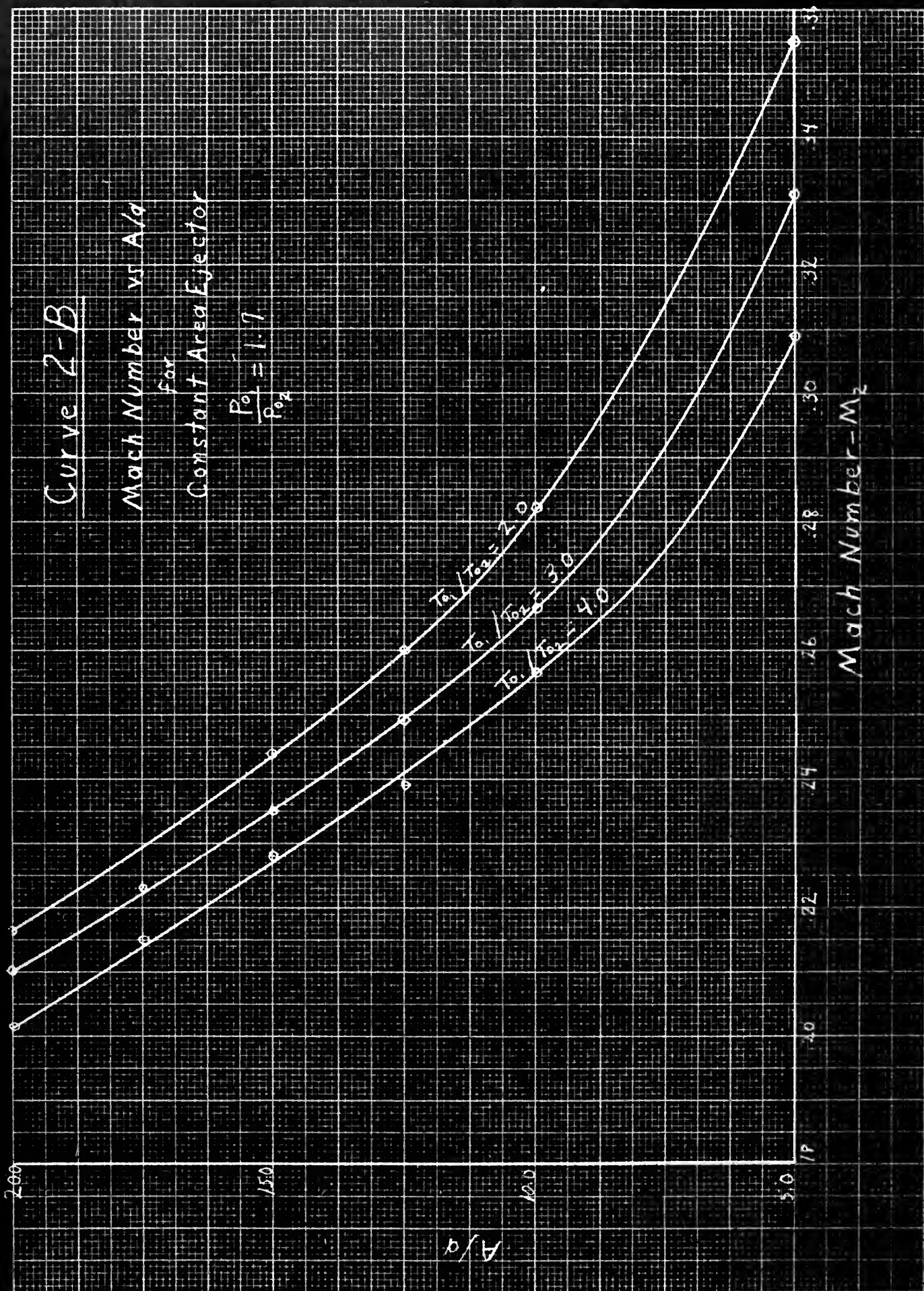




# Curve 2-B

Mach Number vs  $A/a$   
for  
Constant Area Ejector

$$\frac{P_{01}}{P_{02}} = 1.7$$



Mach Number -  $M_2$

$A/a$



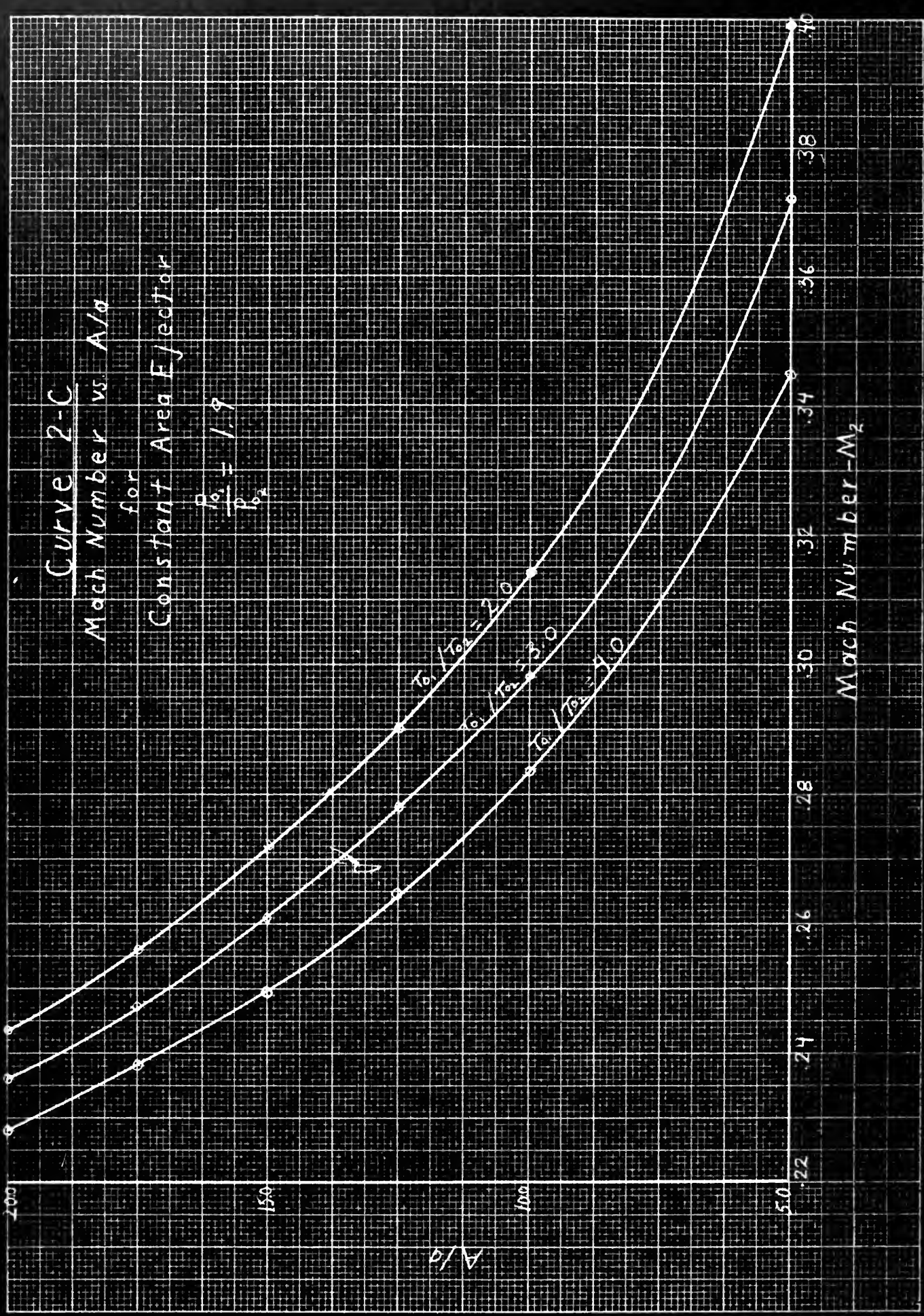


# Curve 2-C

Mach Number vs.  $A/a$

for  
Constant Area Ejector

$$\frac{P_{01}}{P_{02}} = 1.9$$



Mach Number  $M_2$





### Discussion of Results

From tables 5, 6 and 7 it is fairly obvious that in all cases the augmentation follows the same general pattern. Plots were made of the effect of the various variables, holding two variables constant and plotting a series of curves of the third variable with the fourth value as the abscissas. These are curves 2-D to 2-G inclusive.

From these curves it is seen that an increase in pressure ratio increases the augmentation. An increase in temperature ratio decreases the augmentation. An increase in mixing throat area ratio increases the augmentation, and an increase in the bell mouth area to mixing length area increases the augmentation.

The following percentage values are representative.

A number of percentage calculations were made and they all were within close range of the values indicated.

#### Effect of Pressure Ratio

$P_o/P_o$	1.5	1.7
$A^1/A$	% of 1.9	% of 1.9
2	60.9	82.3
4	60.7	80.7
8	61.4	82.0
12	61.7	81.8
16	61.5	81.4
20	61.1	82.0

$$T_{o1}/T_{o2} = 2.0 \quad A/a = 15.0$$



## Effect of Temperature Ratio

 $T_{01}/T_{02}$ 

3

4

 $A'/A$ % of  $T_{01}/T_{02} = 2$ % of  $T_{01}/T_{02} = 2$  $P_{01}/P_{02} = 1.7$  $A/a = 15.0$ 

2	91.4	88.1
4	94.3	88.9
8	92.4	88.1
12	93.0	88.3
16	93.4	88.6
20	93.1	87.8

Effect of  $A'/A$  on Thrust Augmentation $A'/A$       % of  $A'/A = 20$  $P_{01}/P_{02} = 1.7$ 

2	54.1
4	80.1
8	91.7
12	96.2
16	98.5
20	

 $A/a = 15.0$  $T_{01}/T_{02} = 3.0$ Effect of  $A/a$  on Thrust Augmentation $A/a$       % of  $A/a = 20$  $P_{01}/P_{02} = 1.9$ 

5	49.2
10	73.3
12.5	83.2
15.0	89.0
17.5	94.7
20.0	

 $T_{01}/T_{02} = 3.0$  $A'/A = 12$

$$V.I = 20 \sqrt{10^3}$$

$$0.1 = A/A$$

$$2 = 20 \sqrt{10^3} \text{ to } 2 = 20 \sqrt{10^3}$$

1.00	4.00	2
1.50	2.25	3
2.00	1.00	4
2.50	0.56	5
3.00	0.33	6
3.50	0.20	7
4.00	0.10	8

Effect of  $\sqrt{A}$  on  $\sqrt{10^3}$  magnification

$$V.I = 20 \sqrt{10^3}$$

$$0.1 = A/A$$

$$0.1 = 20 \sqrt{10^3}$$

1.00	2
1.50	3
2.00	4
2.50	5
3.00	6
3.50	7
4.00	8

Effect of  $\sqrt{A}$  on  $\sqrt{10^3}$  magnification

$$0.1 = 20 \sqrt{10^3}$$

$$0.1 = 20 \sqrt{10^3}$$

$$0.1 = A/A$$

2.00	2
2.50	3
3.00	4
3.50	5
4.00	6
4.50	7
5.00	8

Thrust Augmentation  
lbs per square inch of Primary Jet

Curve 2-D  
Effect of Pressure Ratio  
on  
Thrust Augmentation

Fixed Conditions:  $\frac{A}{a} = 15.0$ ,  $\frac{T_{01}}{T_{02}} = 2.0$

10.0

8.0

6.0

4.0

2.0

$P_{01}/P_{02} = 1.9$

$P_{01}/P_{02} = 1.7$

$P_{01}/P_{02} = 1.5$

Values of Area Ratio -  $\frac{A'}{A}$

0

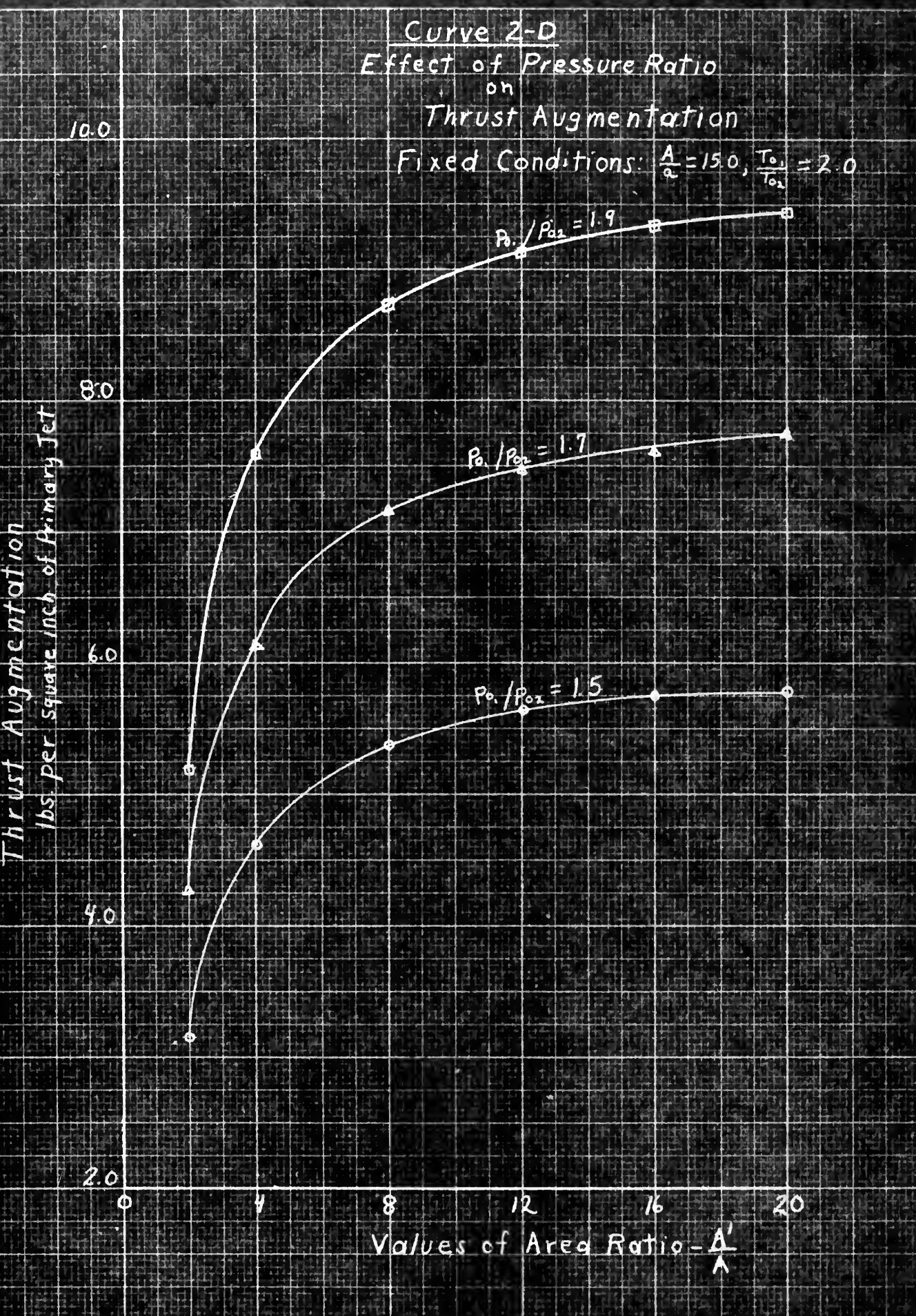
4

8

12

16

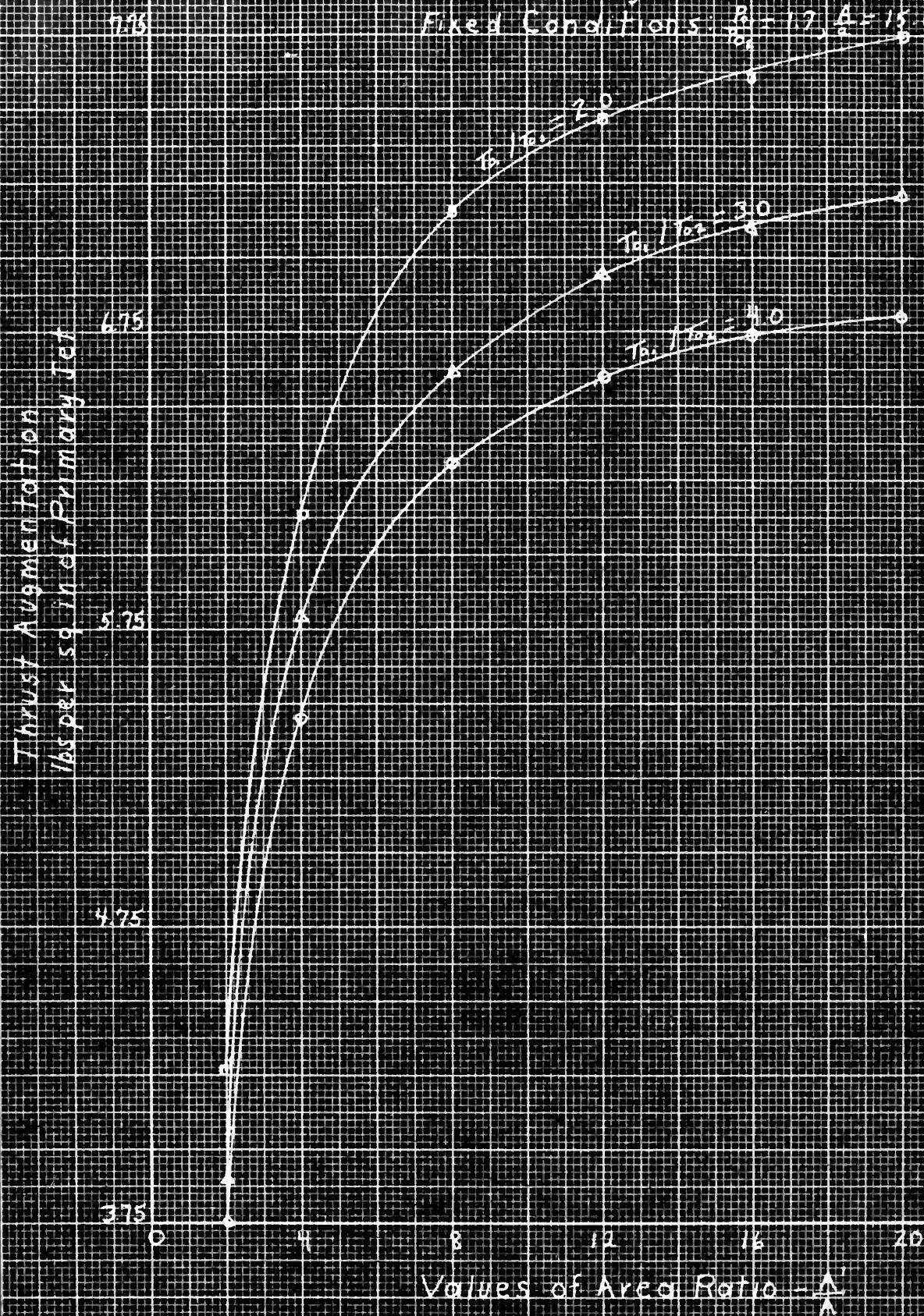
20







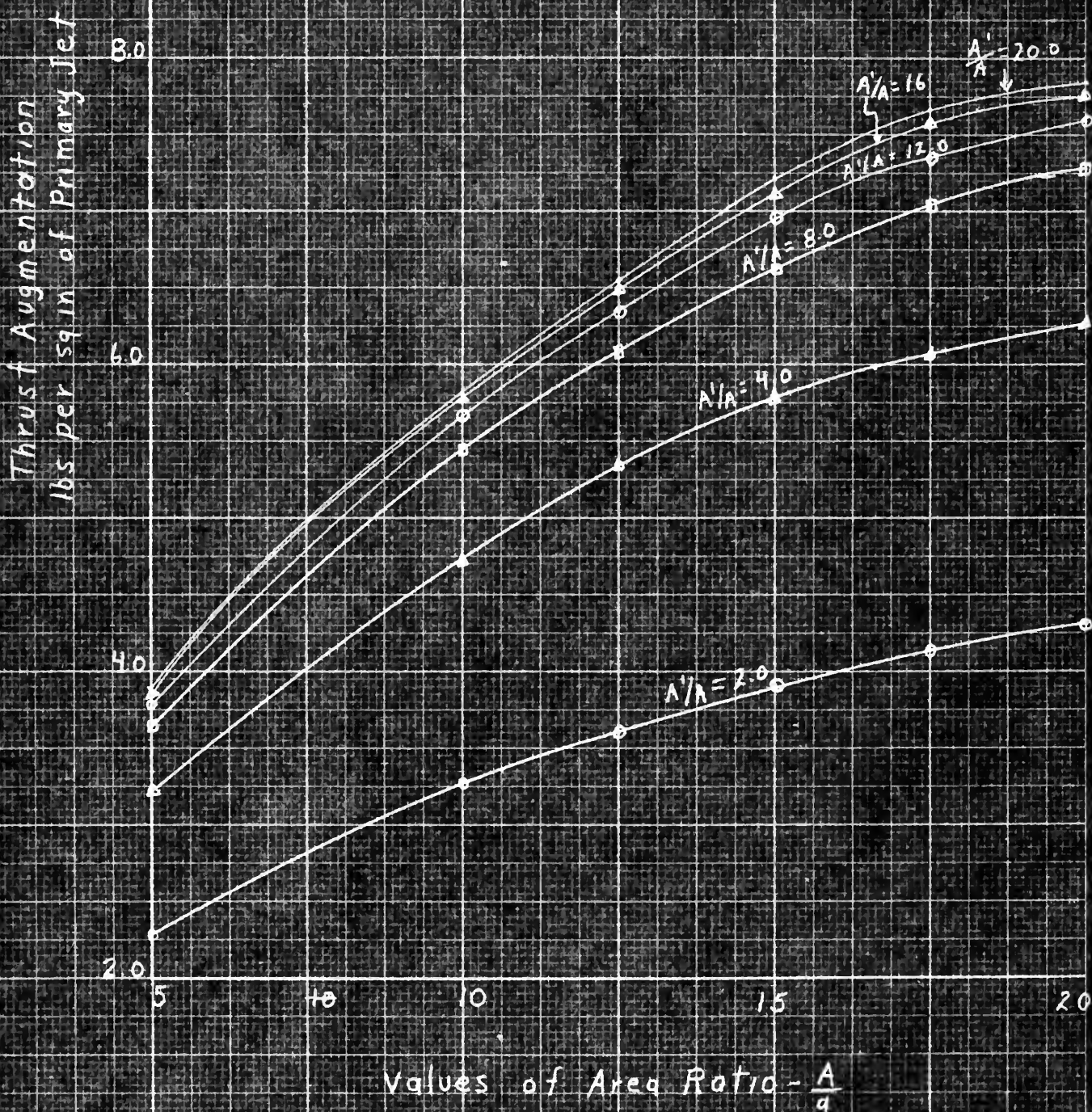
Curve 2-5  
 Effect of Temperature Ratio  
 on Thrust Augmentation  
 Fixed Conditions:  $\frac{P_1}{P_2} = 17, A = 15.0$





Curve 2-F  
Effect of "Bell Mouth" Area Ratio  
on Thrust Augmentation

Fixed Conditions:  $\frac{P_0}{P_2} = 1.7$ ,  $\frac{T_0}{T_2} = 3.0$

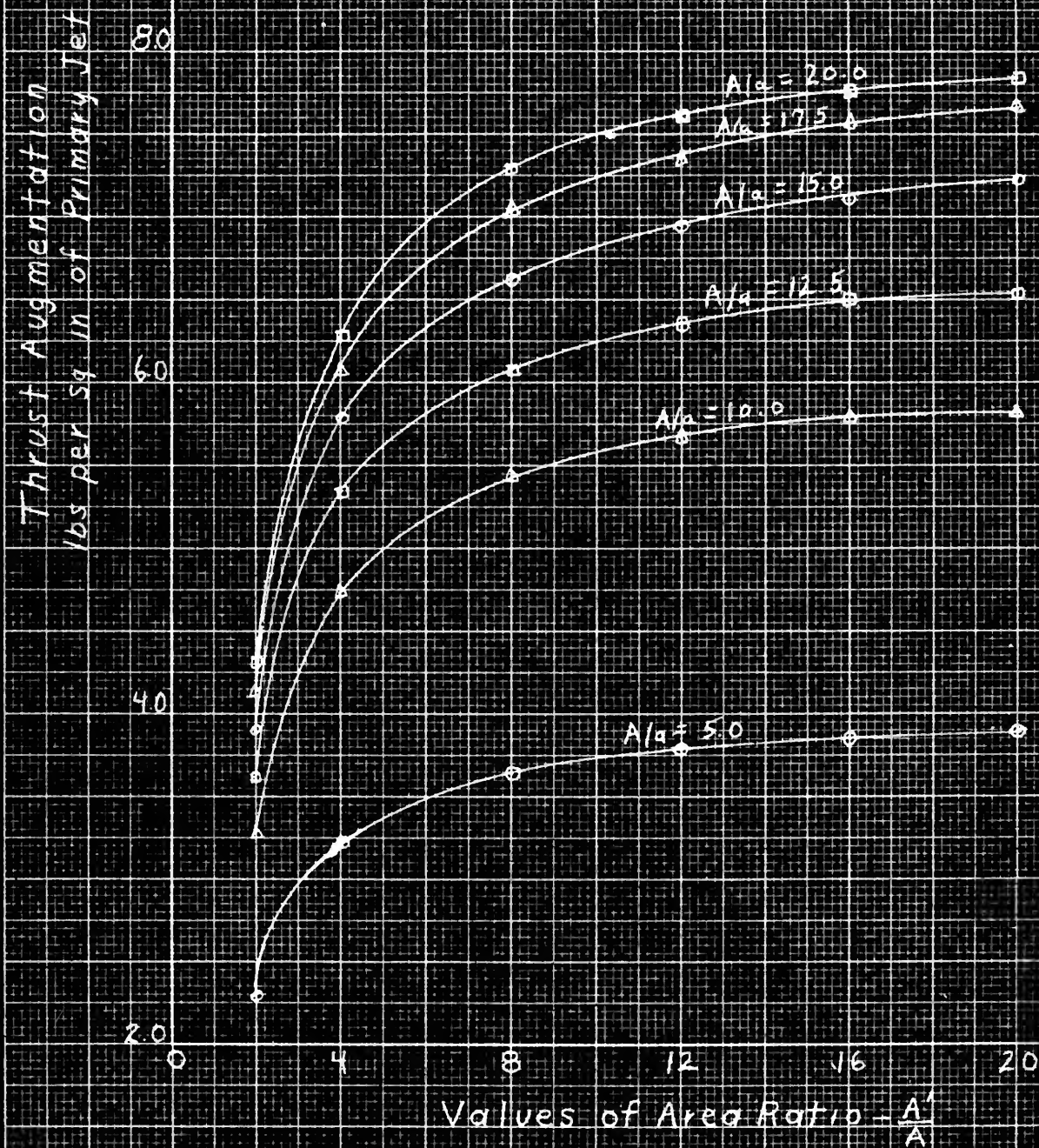






Curve 2-G  
Effect of Mixing Length Area Ratio  
on Thrust Augmentation.

Fixed Conditions:  $\frac{P_2}{P_1} = 1.7$   $\frac{T_0}{T_1} = 3.0$







### CONCLUSIONS

In designing a thrust augmentor the initial conditions of pressure ratio and temperature ratio would probably be fixed within narrow limits. This would set the conditions of two of the variables. However, if these two are permitted to be varied it appears that it would be wise to pick the highest pressure ratio available with the lowest temperature ratio. Since this is an anomaly the percentage figures indicate that of the two pressure ratio is far more important since a .2 change in pressure ratio increases thrust augmentation by approximately 20% but that a change in temperature ratio of 1 means only a 3 or 4% change in augmentation. It appears then, that temperature ratio as a variable is of relatively minor importance.

With temperature ratio and pressure ratio fixed, the other two variables are concerned with the physical limitations of the augmentor. Since in most cases weight and size limitations would make desirable a small augmentor it would be best to choose as small an area ratio as is practicable with performance characteristics. From the percentage calculations it is seen that an increase in the area of the bell mouth does not give a proportionate increase in thrust as it is increased above  $A'/A$  of 8. For a two and a half times increase in  $A'/A$ , the thrust increases only about 8%. As the size of the ratio approaches 20, the percentage increase in thrust augmentation is very

It appears from the foregoing that the relative values of the two variables are not constant, but that they vary in a systematic manner. The relative values of the two variables are constant only in the case of a linear relationship, and in this case the relative values are constant for all values of the independent variable. In the case of a non-linear relationship, the relative values of the two variables are constant only for a limited range of values of the independent variable. The relative values of the two variables are constant for all values of the independent variable only in the case of a linear relationship, and in this case the relative values are constant for all values of the independent variable.

10. The percentage increase in actual production is very

small. It can be concluded that a value of  $A'/A$  of from 8 to 10 is most practical. It is interesting to note that an  $A'/A$  of only two (which would mean a radius ratio increase of only 1.4) gives more than 50% of the thrust of  $A'/A$  equal 20.

Changes in  $A/a$  have a greater effect on augmentation. Increasing the ratio from 5 to 20 gives 50% more thrust. An  $A/a$  of 15 gives about 90% of the thrust obtainable from  $A/a$  of 20. It can be concluded that an  $A/a$  of 20 is probably the best but if space is limited an  $A/a$  of 15 will lose only 10% of the thrust.

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Investigating the value of the 500 most valuable companies

is a of 12 given below in the form of a table.

1/4 of 20. If you're wondering what 1/4 of 20 is

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